THE FUNDAMENTAL LAWS
OF HUMAN BEHAVIOR

MAX MEYER
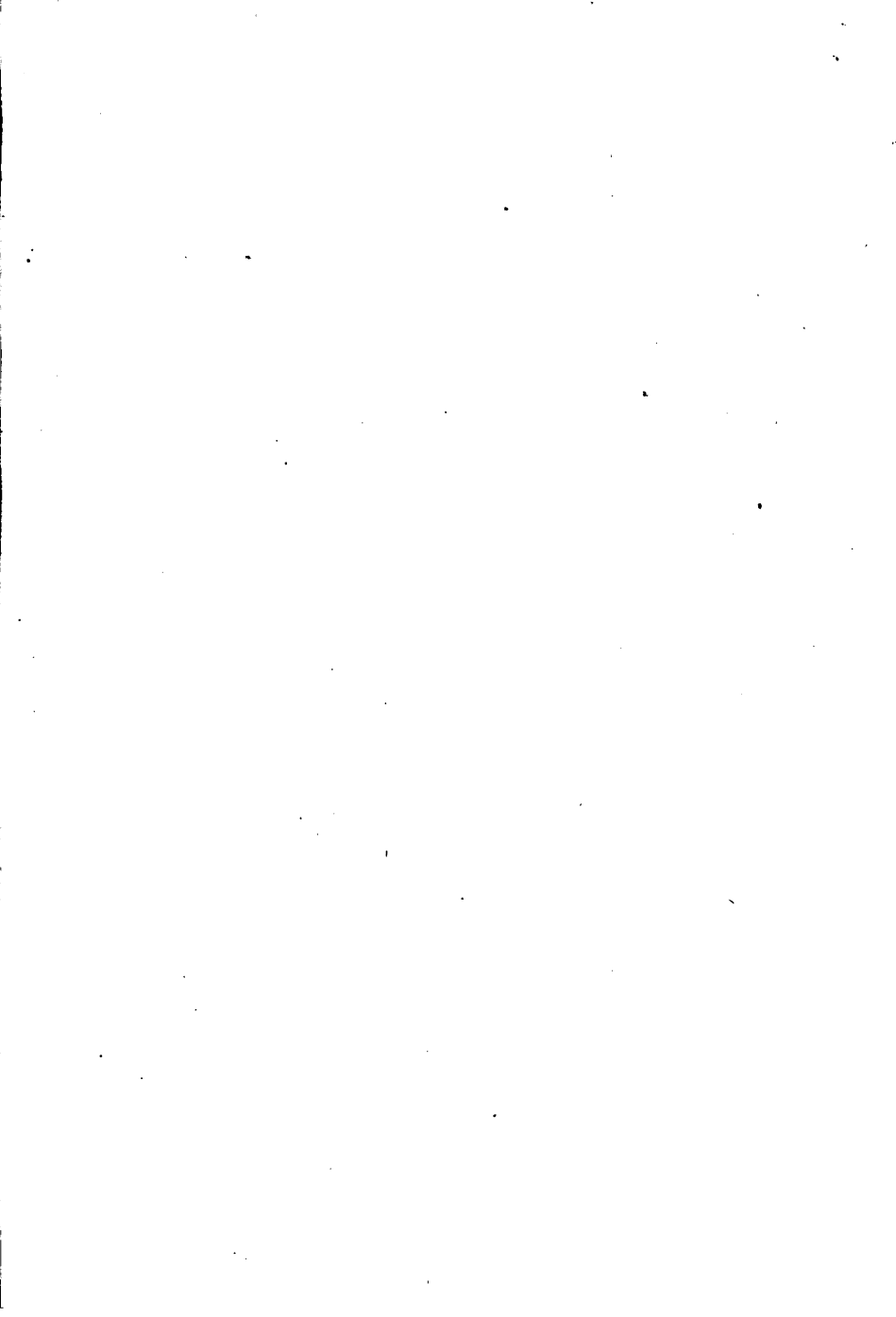
THE FUNDAMENTAL LAWS OF

HUMAN BEHAVIOR

Lectures on the Foundations of any
Mental or Social Science

by

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ARTI et VERITATI

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PREFACE

THE complete dependence of all human activity on the functional properties of the nervous system and on the *changes* which these functional properties undergo during life, is much emphasized in innumerable treatises written by physiologists and psychologists. Yet the way in which these changes come about is described in such vague, subjective terms, that the changes, the "education" of the nervous system, appear to the young student as mysterious, as miraculous, as unreal, almost incredible, after the reading of these treatises as before. Let me quote from such a treatise by a distinguished physiologist—very admirable and very convincing provided one is convinced even before reading it—the following sentences: "As a result of experience, definite tracks are laid down in this system. - - - The candle flame injures the skin once when the finger is brought into contact with it. The one act of injury which has followed the first trial of contact suffices to inhibit any subsequent repetition of the act." Such a description of the matter does not clarify it to the young student, but merely substitutes for the mystery which from ancient times has surrounded it, another mystery clad in modern terms. "Experience" is spoken of as if it were a concrete reality, a powerful agent producing changes, instead of making it clear that experience is only an *abstract name* for the very fact that these changes occur. "Injury" is said to inhibit an act, but the student is left to look in vain for an

analogy among the objective realities he knows, where an injury received by machinery results in the reversal of its motion. A stick of dynamite placed on a rail certainly does not cause a locomotive to stop, the next time, before touching it. The mystery can be removed from human activity only by offering the student *concrete, although perhaps hypothetical, images* and uniting these into a system no more complex than the machinery which moves about him everywhere in his every-day life.

To make clear the functional changes which occur in the nervous system and which, determining the individual's life activity, are of tremendous importance to the individual and to society, it is necessary and customary to use diagrams of the nervous system. I have used such diagrams of my own design in this book too. I am prepared for hearing from anatomists and perhaps even from physiologists and psychologists the judgment that my diagrams look queer, that they do not reproduce what one sees in the dissecting room with and without a microscope. I confess that I have committed this sin with the full conscience of what I am doing. It is customary, in the diagrams which illustrate nervous functions, to imitate the actual curving of the nerve fibers passing from the spinal cord to the brain and here from lobe to lobe. But I am convinced that this is not only unnecessary, but even harmful. In this book the diagrams illustrating function have been entirely separated from those illustrating anatomy, and the former have been designed exclusively with a view towards making clear the fundamental laws of learning. However queer they may look to the anatomist, they will be the more useful to the student of human activity for whom this book is written, because they will free him of the tendency to burden his mind with irrelevant curves resulting from mere accidents of growth.

What this book proposes to do is essentially an investigation into the problem contained in the following question: What are the simplest assumptions, necessary and sufficient, to explain hypothetically the facts of human behavior as dependent on the function of the nervous system? Having answered this question, it attempts to illuminate the deep-rooted habit of describing human behavior as dependent on subjective states, on states of consciousness,—a habit which still largely governs the sciences of human society, preventing them from throwing off the shackles of subjectivity.

My thanks are due to my wife for aid and advice in preparing this book; and to my assistant, Mr. A. P. Weiss, who drew the illustrations, for his devotion to this work.

M. M.

FIRST LECTURE

Being, doing, thinking. Thinking of humanity in terms of thought. The subjective and the objective. Consciousness and nervous function. The nervous system compared with a telephone system. Designing a nervous system. Sensitivity, contractility, conductivity. Differentiation of tissues. An analogy of tissue conductivity. Deformation of the body bringing about change of its situation. Avoiding an obstacle. The story of the snail. A nervous system of impossible design.

W HEN we meet one of the things which surround us in nature, we ask, perhaps more frequently than any others, one of these three questions: What *is* it? What does it *do?* What are its *thoughts?* We know many things with respect to which the first is the only question we ask. We pass through a street which is being paved. When we are told that the blocks of stone put down in regular rows by the workmen, *are* granite, we are probably entirely satisfied. But when we approach a mill and see the wheels turning, we are not satisfied when we know only that it *is* a mill. We desire to know what it *does*, for example, whether it is likely to injure us if we step nearer, or whether it can do special work which we need to have done. When a cow or bull crosses our path, we are again not satisfied if we know only the animal's name. We are much concerned with the animal's action. Will it compel

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us to change our direction, or can we safely remain where we are? When, thirdly, as school children, we are with our teacher in the class room, we are greatly interested, not only in what he does, but still more so in what he *thinks*. If he thinks well of us, we are glad. But let us raise the question how we know whether our teacher thinks well of us or not, and we must admit that we can not directly know his thoughts, that is, *have his thoughts* any more than he can *have our thoughts,*—that we know it only through our observations of what he *does* in giving us things, in writing what we may read, in speaking what we may understand. Yet if we are asked whether we are chiefly interested in our teacher's acts or in his thoughts, we are probably quite ready to assert that we regard his thoughts, the existence of which we can not directly know, but only assume, as of far more importance to us than his acts, which we do know directly. In this apparent contradiction lies in a nutshell the problem with which we have to deal in this book. Why do we think of humanity almost exclusively in terms of thought, although our experience contains no other person's thought, but only his behavior? Many other examples could be used to show that a person's *thoughts*, which nobody can have but himself, are nevertheless of the greatest concern to others who can not know them, can not have them. When parents send their children to school, they send them in order that their intellects may be trained, their characters developed. Let us inquire what is meant by such words as intellect and character. The dictionary tells us that they refer to thought processes, not to particular activities or to a person's appearance. The most important training, then, which every parent strives to give his child, is a training of his powers of thought, of this mysterious unknown,

Not infrequently we hear people speak of brain work and of manual labor. We hear them distinguish between brain workers and those who work with their hands. The distinction seems quite acceptable. Of course, those who use these phrases do not mean that they know much about the workings of the brain. They simply mean that certain persons, although they do not do much which can easily be seen, are nevertheless active in that they think. They work mentally, as we say. And for this mysterious unknown they often receive a high salary.

Very common is this emphasizing of thinking, this complete or relative disregarding of an individual's doing or being, in ethical valuations. A boy has placed a plank across the street car track and derailed the car. He tells us that he thought that the foundations of the bridge a little distance away had been washed out and that he intended to stop the car and save our lives. Whatever may be the facts in the case, that is, the doing and the being of the water, the bridge, the car, and the boy himself,—we probably praise him for his thoughts and intentions. Or, the boy tells us that he wished thus to injure and punish another boy whom he saw as a passenger on the approaching car. Whatever may, again, have actually happened, visibly and audibly,—for the boy's thoughts we have only contempt, we call them wicked. Yet the boy's being and doing is the same in both cases: he looks the same and he has placed the same plank in the same manner across the track. It is again this mysterious unknown, his thoughts, which concerns us chiefly.

The most conspicuous example, perhaps, is to be found in religious doctrines and ideals. Not good works, but faith decides the test which the Christian has to undergo, according to the Apostle. Not what man does, or what he is, gives him his religious qualification, but his faith,

that is, his thoughts, again this same mysterious unknown.

In none of these examples are anyone's thoughts known to, that is, had by, any one other than himself. Even an Inquisition, which has power over life and death, is unable to find out what is *thought* by those whose religious or irreligious thoughts it pretends to investigate. It can find only what is done by them, including, of course, under *doing* what is written and spoken.

For more than two thousand years a science has existed which has devoted itself to the mysterious unknown which we have just characterized by examples. One may give it the name of mental science, or, rather, mental sciences, for in our modern times science is breaking up into many branches, according to the diversified interests of mankind and in consequence of the limitation of individual mental capacity. Until quite recent years these mental sciences were based upon the conscious experiences of the individual who "professed" the science, upon introspection. During the last few decades the conviction became general that a science of *the subjective*, an introspective science, because of its limited possibility of generalization, hardly deserved the name of a science. In order to remedy the defect which had been discovered, objective methods, like those used in the physical sciences, were introduced into the mental sciences, to supplement the subjective method of introspection. In the following pages we shall attempt to study by objective methods the most fundamental *objective* facts which are related to *subjective* phenomena, and as comprehensively as possible to make clear this relation between objective facts of *being* and *doing* and the subjective experiences of our own *thinking*.

No other fact concerning the relation between *the*

subjective (the individual consciousness) and *the objective* (the world of the natural sciences) can be more impressive, than that consciousness seems to be entirely or, at least, relatively dependent on, conditioned by, the function of an individual's nervous system. So generally is this recognized, that even the extreme assertion that consciousness is impossible without the existence and function of a nervous system, would undoubtedly find a majority of votes among scientists.

This will justify—if for the present such a justification seems necessary—our beginning with the study of the nervous system's significance for the being and doing of those objects in nature which are known to possess a nervous system.

We may compare a nervous system with the telephone system of a city or even of a nation, which enables a person to give orders in one place and have them received and executed in another. A nervous system consists essentially of an immense number of string-like structures, very fine and relatively very long, just as a telephone system consists essentially of a large number of conducting wires. However immense the number of these strings may be, they are never found as a disorderly mass, but always arranged according to definite rules. For the sake of understanding clearly the significance of their architectural arrangement for the behavior of an *animal*—we know that all those things in nature which possess a nervous system, and even many without it, are called animals—let us imagine that we have the duties of a creator and that we have to furnish a given animal with a nervous system of our own design. How, then, should we systematize, that is, put together into a unit, all the strings which we are to insert into the animal's body? The simplest plan seems to be that of uniting all the strings so that one of

the two ends of each string is located in a single point of
the body, whereas all the other ends are left unconnected
and are distributed among the various parts of the body,
like the diagram of Figure 1.   Suppose we offered an
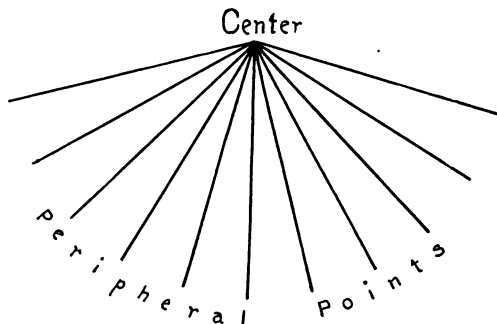
FIG. 1—An impossible nervous system.

animal which has thus far been without a nervous system,
a nervous system of this design.   Should the animal be
grateful for our gift?   Would this gift be helpful to the
animal in its struggle for life?

In order to answer this question, we must first gain
some insight into the life, the being and doing, of an
animal which possesses no nervous system.   Let us make
ourselves familiar with the behavior of a simple animal
which we all greatly admired in our childhood days, the
snail.   It is true, the snail does have a rudimentary kind
of a nervous system.   But the snail is anatomically so
simple that it could almost equally well get along without
it.   That snail, then, of which we shall now speak, is
indeed only an imaginary snail but near enough to reality
to serve as an example for the demonstration of certain
general laws of animal behavior.

We recall that among the main properties of living
matter are sensitivity, contractility, and conductivity.

In the lowest forms of animal life every particle of the body shows all three of these properties about equally. In the higher forms of animal evolution this is quite different. Our muscles, for example, have but little sensitivity and conductivity. At the expense of these two the third property has been so much increased that the muscles may be called the contractile tissue of our body. In such a case we speak of the differentiation of tissues. Muscular tissue has become differentiated from the rather uniform tissue of lower forms of life, just as in modern society the individual has become differentiated and can, for example, make excellent shoes, but no clothes to cover the other parts of the body, whereas the undifferentiated savage makes tolerably good clothes for himself as well as shoes.

Differentiation of tissues is, of course, not restricted to the one kind just mentioned. Other tissues lose most of their contractility, but become the more capable of conducting any process which happens to go on in one point of them to all their other points. This does not mean that the velocity with which the excitation travels in them becomes much greater. Analogies from physics and chemistry make it fairly certain that the velocity of conduction, the velocity of the current, remains about the same. But the resistance of the conducting tissues becomes much less. Such tissues are the nervous tissues, those strings of which we spoke above and about which we shall have to say much more further on. The main property of nervous tissue is its conductivity, by which the strings are capable of serving like telephone wires conducting electric currents. It is important that, in thinking of increased conductivity of tissues, we do not think of increased velocity of conduction. While we need not deny that the velocity of conduction may be somewhat

affected by this differentiation, what we mean chiefly is that the excitation is offered less resistance by the nervous tissue than by any other tissue, that it travels through nervous tissue, not more quickly, but certainly more strongly, more effectively than through the non-conductive tissues.

Other tissues, again, differentiate in such a manner that they obtain a highly increased sensitivity at the expense of their other properties. Think of the ease with which we find our way on a dark night when, during new moon, only the stars aid us with their faint light. The sensitive elements on the retina, the background of our eye, respond even to this faint light and stimulate the nerve ends which, through their conductivity, enable the various parts of the body to execute the proper movements. These three properties, however, sensitivity, contractility, and conductivity, are by no means the only properties of living matter. They are merely those properties which chiefly concern us in our present study. In addition, there are many other properties of less importance for our present purpose. If we desire to know more about them and the various ways in which tissues differentiate, we must consult the text-books of the sciences which are devoted to these problems, namely, histology, the science of tissues, and biology and physiology, the sciences of the function of living matter.

We mentioned that the main property of the string-like elements which make up the nervous system, is their conductivity. Let us now apply this knowledge to our problem of the acceptability or non-acceptability of the gift which we offered to our imaginary, nerveless snail. There is, according to our assumption, and, indeed, practically in accordance with the actual facts, no differentiated tissue in the snail's body. Each particle is

sensitive, each particle contracts when stimulated, and each particle conducts what goes on therein to the neighboring particles, causing the same process in them.

Suppose, now, the snail, spread out over the ground as when creeping, is very gently touched at the point of the tail end marked in Figure 2.   Owing to its sensitivity,
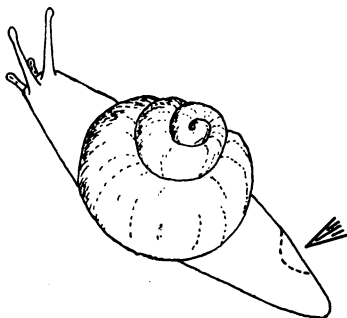
Fig. 2—Simplest motor response of a snail.

the tissue touched responds. Being contractile the tissue responds by contracting, so that the tail assumes an unsymmetrical form like the one shown in possibly exaggerated manner by the dotted line in Figure 2.   The excitation, first caused in the part touched, spreads in consequence of the conductivity of the tissues. What this conductivity means may be made clear by an example taken from ordinary experience.   If we drop a small quantity of syrup into a glass of water, we can see how it gradually spreads through the whole fluid until the chemical constitution, different just after the drop fell, again becomes uniform all through the fluid.   When we speak of an "excitation" caused in a tissue by a touch, this means, too, that the chemical constitution of the point touched has been changed and that this change tends to spread wherever it can, until the constitution has again become

uniform everywhere. This spreading is meant when we speak of the conductivity of the tissues. The excitation, then, spreads from the contracted part to all the other parts of the animal's body. Wherever it reaches, contraction of the tissues occurs. But, naturally, just as the syrup spreading out through the water becomes more and more dilute at the starting point, so the excitation spreading out through the body becomes weaker and weaker at the starting point. Finally, perhaps after a second or two, the intensity of the excitation has become quite uniform all through the body, and the contraction, the density of the tissues, has also become equalized all through the body. Only the deformation of the body surface and a weak uniform excitation and contraction of the whole body remain as the effect of the touch.

Now, the chemical state which we have called excitation, means the presence in the tissues of chemical substances which are not normally there. It is natural, then, that the forces which are always active in living matter will tend, after the external influence has ceased, to bring about such spontaneous chemical changes that the normal condition is restored. Gradually, therefore, the normal chemical constitution of the body returns, and as it returns the state of contraction disappears. The body expands again. However, since the previous *contraction* had become practically *uniform* in a *deformed* body, the expanded body, having regained its normal shape, no longer has its previous *situation*. The deformation by the sudden shrinking occurred on one side; the reformation of form by expansion occurred on all sides of the body. Its axis has slightly turned in the direction indicated by the two arrows perpendicular to the axis of Figure 3.

The application of the few and simple facts which we have just learned, at once reveals their great importance.

We desired to gain some insight into the life of an animal which possesses no nervous system, in order to answer the question whether a particular nervous system with
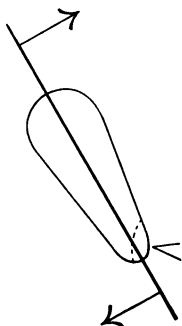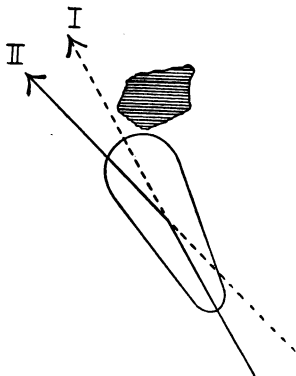
FIG. 3—Snail turning.   FIG. 4—Snail avoiding a rock.

which we intended to furnish the animal, would be an acceptable gift to the animal or not.   The most important activities of an animal are plainly those of protection and of nutrition.   Let us see if we can comprehend the behavior of our snail when it is either in search of food or avoiding an injurious object.

Suppose the snail is creeping on the ground in the direction of the arrow I in Figure 4.   Let us take the mechanics of locomotion in the forward direction for granted, so that we may take up at once the more special problem which concerns us here.   The snail, creeping forward, approaches the stone which accidentally lies in its way, and the right side of the head comes into contact with the stone.   (For simplicity's sake we assume that our imaginary snail has no tentacles.)   We know now, from our previous discussion, what must happen.   The part which has been excited by the touch of the stone,

contracts. A little later, expansion of the body occurs, but expansion not only of the part near the stone but of all the body with practical uniformity. The result is a change of position. The axis of the snail now assumes a position more nearly that of the arrow II. The internal conditions—whatever they may be—which caused the original forward movement, again become effective. The snail, moving forward, perhaps again comes into contact with the stone. The same happens as before. The axis again turns toward the left. Again the forward movement begins and now, perhaps, is continued without touching the stone; the actual path being approximately that indicated by the solid line.

All this is by no means an extraordinary event in the animal's life, an unusual kind of behavior. It is practically the complete story of the snail. The snail, in order to live, must eat. Lack of food, continued for some time, results in chemical changes in the body. In consequence of structural and functional properties of the body which we cannot study here, these chemical changes bring about a forward movement. A rock (or any other obstacle) lies in the way. If the rock could permanently stop the forward movement, the snail would starve to death. But, in one or several stages, a change of the situation is brought about by a change of the direction of the animal's axis. Now the snail creeps on. Other obstacles which may be encountered are taken in the same way. On its forward march the snail, by accident, sometime passes over edible substances, which stimulate the mouth organs and, consequently, are consumed. Later, lack of food brings about locomotion again, and the same things happen in the same cycle.

One may feel inclined to exclaim: An animal's life cannot be so simple, so automatic as that,—dependent

on the mere accident that food substances should be in its fortuitous path! But why not? It is true, many a snail will fail to come across any food substances and die of starvation. Such is life! But enough will have better luck and live to propagate the species, for food adapted to the needs of snails is common on earth.

Not only food is obtained in this—if one wishes to call it by that name, mechanical—way; protection against injury is thus made possible too. If the snail instead of approaching a rock, had come near a directly injurious substance, it might have changed its route even before touching that substance; for the tissues of its body are excited, not only by touch, but also by many other influences, for example by a change of temperature, or by the effect of a volatile chemical substance. A piece of camphor instead of a rock would have turned the snail some distance before touch would have been possible. Another important method of protecting itself is that of completely retiring within its shell. This again requires no additional mechanism. We supposed above, that the touch of which we spoke was a very gentle touch. It will, of course, always be gentle if it results from the snail's—this slowly moving animal's—own motion. If the touch is relatively strong, as when a child touches the snail with a straw, the excitation resulting and spreading with great force all through the tissues must cause, not only the tissues at the point of contact, but also the neighboring tissues, possibly all of the body, to contract vigorously. If the whole body contracts strongly, it must, since a part of it is attached to the interior of the shell, necessarily disappear in the shell. It is to be noted, however, that one kind of behavior is impossible in this kind of an animal, namely, stimulation occurring at one point of the body and contraction occurring exclusively

at an entirely separate point of the body. There must always be what may be called a wave of both excitation and contraction, spreading from the point of stimulation more or less—so little, indeed, in some cases that contraction may seem to be confined to the point of stimulation, or so much in others that clearly the whole body is involved. But the point of stimulation can not in any case fail to be included in and to be the center and starting point of the wave of contraction. Nevertheless, a snail does not need a nervous system in order to live. It can behave in the way in which we have described it as behaving without possessing nervous tissues of any kind whatsoever.

Nevertheless we may wish to appear generous and offer our snail the nervous system of our design in Figure 1. Although the snail can get along without a nervous system, why should it not get along even better when in possession of our gift, we might naively ask. Imagine the snail had accepted the gift and were approaching the rock in Figure 4. The moment when the contact occurs one of the peripheral ends of the nervous strings is excited. The strings are so differentiated that they have an immensely greater conductivity, that is, lesser resistance, than the undifferentiated tissues. The excitation, therefore, is conducted to the point where all the nervous strings are connected and thence with great intensity of flux along all the nervous strings, thus reaching effectively all the parts of the body. Consequently, all the parts of the body contract practically at the same time with great force. A prompt and relatively strong contraction at the point of stimulation, followed slowly by a weak and uniform contraction of the whole body is no longer possible. The resulting change of position is also impossible. The whole body contracts and, after a while, expands again,

to touch, of course, the rock in exactly the same way that it did the first time. In consequence of the touch, the whole body contracts again. It expands again, contracts again, expands again, contracts again, and so on *ad infinitum*, until the animal is either exhausted or starved or both. Any way of avoiding the obstacle is impossible. It is clear, then, that the snail would be very much worse off with this kind of a nervous system than without any. Without any nervous system it can live quite well, unless it happens to have exceedingly bad luck. With this nervous system it can not live any more than a human being could live who, whenever he saw or heard anything, instead of normally responding to the situation presented, would invariably have an epileptic fit, a violent and entirely useless unadapted muscular contraction.

SECOND LECTURE

Contraction at a point other than that of stimulation. The moth and the light. A steady stimulus causing a periodic motion. The need of a nervous system proportional to the development of special motor organs. Sensory and motor points of the body. Nervous connections represented graphically by arches. Cells the biological elements of structure. A nerve cell not a cell but a part of a cell. Neuron, fiber, ganglion cell. Types of neurons. Collaterals. Terminal arborization and dendrites. White and gray matter. Relative unimportance of the ganglion cell for a theory of mental life.

LET us consider, quite apart from any special problem, in what manner and for what purpose strings conducting like telephone wires could be serviceable in an animal's body. It is plain from the foregoing that they are needed only in case the contraction is to occur not at all at the point of stimulation, but at some other point. This can be brought about only by conducting away the excitation from the point of stimulation by string-like tissues which cannot themselves contract, but possess a greater conductivity than ordinary, undifferentiated tissues. Carried to another point, the excitation can there cause the contraction desired. This kind of function is necessary in all the more highly organized animals. Take an insect, a moth for example. We know that the most striking behavior

of a moth is its flying towards any source of light. This is the result of the nervous connections between the wings and the eyes. The right eye is connected (if not exclusively, at least better) by nervous strings with the muscles of the left wing, the left eye with the muscles of the right wing. If the moth has the source of light on its right side, the right eye receives more light and consequently a stronger excitation than the left eye. The left wing then beats the air more forcefully than the right wing, and the axis of the animal is turned to the right until both eyes are excited by the light with equal intensity, that is, until the moth flies directly towards the light.

We need not discuss here the question as to the value of this instinct (instinct is the name given to such connections between sense organs and motor organs) to the moth. We may take this value for granted in spite of the fact that millions of moths are destroyed because of this instinct of flying toward the light. Sources of light destructive to moths on the surface of the earth are a very recent invention of mankind, for which nature cannot be expected to have made provision in giving the moth its biological inheritance. It is not difficult to imagine that this flying in the direction of more strongly illuminated or lighter objects rather than of darker ones aids the moth in obtaining food. So much is plain that it could do a moth, whose anatomy is (relatively) so highly developed, no good whatsoever if an excitation caused by light in the region of the head would cause a contraction of the tissues located in the same place. In order to be of any value to the animal it is necessary that the chief sensory areas, the eyes, and the chief motor organs, the wings, be connected with each other by differentiated tissues of the conducting kind, by nerves.

It may not be amiss, even at the danger of getting a little side-tracked, to discuss another fact which is of great significance for the behavior of animals. We said that the movement of the moth's wings was caused by the excitation occurring in the eye. The question may be asked: How can a rhythmical movement like that of the flapping wings be caused by a continuous excitation like that in the moth's eye? We have no need to explain this here in detail, but it is important to point out, that such a transformation of something continuous into something discontinuous is an exceedingly common occurrence in nature. It is especially important to note that it occurs in the inorganic world, the dead part of nature, as frequently as in the organic world, in living nature,. so that we cannot be accused of having neglected the possible claims for recognition of any so-called vital or mental forces when we simply stated that the wings flapped merely because of light falling steadily on the animal's eye. Let us take from the inorganic world a few examples. The wind passing steadily over the surface of the ocean does not cause, by friction, simply a motion of the surface water in the same direction and a compensatory movement of lower layers of water in the opposite direction. It causes, as we all know, a motion of the particles of water which takes place, only to a slight extent in the horizontal direction of the wind, mostly in a vertical direction, up and down, causing waves which periodically rise and fall a considerable height. Or, when we blow a whistle steadily, the result is a rhythmical movement of the particles of air enclosed in the whistle, a physical sound. When water flows very slowly from the faucet in our kitchen, it does not fall in a continuous and very narrow stream, but in periodical drops. Air blown under water through a tube, similarly rises in periodical bubbles.

Nobody thinks that such a transformation in these cases requires any hypothetical vital or mental forces. To assume any such forces in the case of muscular activity is equally unnecessary. What we have said about nervous excitation in the eye causing rhythmical motion of the wings is really all that need be said, unless we are specially interested in the details of physiological science.

Let us return to our problem as to the kind of a nervous system which could be regarded as an acceptable gift by our snail or any other animal. We saw that only one kind of behavior is *impossible* to the snail without a nervous system, namely, a contraction at one point of the body in response to an excitation started at a different point, without any contraction occurring at this latter point, or at least, without a contraction occurring at the point of stimulation with any force approaching that of the contraction at the former point. For example, if the tip of one of the tentacles of a snail—let us think of a snail with tentacles—is affected by a certain stimulus, say fire, it might be safer for the animal to respond by a strong backward movement of its locomotor organs, however far these are from the point of stimulation, than to respond strongly by a contraction of the stimulated tentacle and weakly by action of the locomotor organs. We see at once the close connection between the existence of a nervous system and of highly developed special organs, especially of locomotor organs. Higher animals, having legs, must indeed, because they have these special organs, respond to stimuli occurring at certain excitable points of the body by a forward movement of the legs, to stimuli at other excitable points by a backward movement of the legs, and by no other motor reaction. The snail, which has scarcely any specialized motor organs, just on this account does not absolutely need

a nervous system. So much nervous tissue as the snail possesses, serves minor purposes which do not much concern us here.

On the other hand, if an animal has specialized locomotor and other motor organs, fins, wings, or legs, with double sets of muscles, for forward and backward motion, its nervous system must be designed according to the following plan and can not be designed in any other way without defeating its purpose. Certain excitable points of the body must be connected by conducting strings with certain contractile tissues located in definite points of the body; other excitable points must be connected with certain other contractile tissues of the body. If we simplify our way of expressing this, we may say: *Each sensory* (that is, excitable) *point of the body must be connected by a conducting string with a definite motor* (that is, contractile) *point of the body.* Let us remember, however, that the facts are not quite so simple as they are expressed in these words. Actually, a single sensory point is scarcely ever excited in isolation, and a single contractile point, a single muscle fiber, never contracts while all other fibers remain at rest. However, general statements of fundamental facts for the purpose of remembering and reflecting upon them in the abstract, are always artificially simplified. Otherwise they would be of little value to our thought, which is limited in capacity. All scientific laws, even the greatest and most famous of them, are artificial simplifications. This justifies, then, our speaking of the connection of one sensory point with one motor point as if such a simple nervous connection were possible.

We may represent such nervous connections graphically as in Figure 5. Each sensory point S is connected with a motor point M by a conductor, represented in the figure,

of course, by a line. That this line has the form of a flat arch is not essential. This special form of the diagram has been chosen here because of its convenience, which will later become even more evident. Since there are a

Se Sd Sc Sb Sa   Ma Mb Mc Md Me
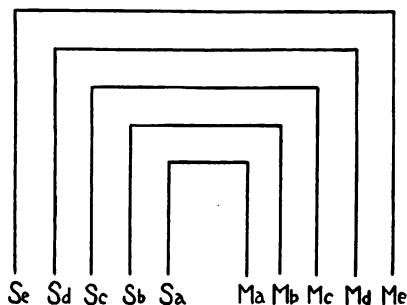
Fig. 5—Neuron arches.

great many sensory and motor points, the diagram ought to contain a great many arches. In our figure they are all represented by only five. They are drawn one above the other because this is the most convenient form of drawing them, not because any such connections are likely to be actually found in a similar parallel arrangement. The difference in size of the arches is also a mere matter of convenience, without any actual meaning. If no other assumptions are made at any later time, we shall always regard the arches as representing nervous connections of the same length.

Let us at once apply this diagram. We spoke above of the instinct of a moth of flying toward the light. Take S_b to be the right eye and S_c the left eye. Of course, an eye is not a single sensory point, but since it functions in this case as a unit, there can be no objection to speaking of it and representing it graphically as if it were a single point. Take M_b to be the left wing's muscles and M_c

the right wing's muscles. Again we understand that the
muscles of a wing are not a single motor point. The
muscles of one wing are, indeed, two sets of muscles, so-
called antagonistic sets, of which one serves the upward,
the other the downward movement. Each of these
muscle sets consists of thousands of muscle fibers. One
fiber or a small group of these fibers may be called quite
correctly a motor point of the body. However, since the
whole double set of muscles functions together, brings
about the definite effect, the flapping of one wing, we may
speak of it here and represent it graphically as if it were a
single motor point. The wonderful instinct of flying
toward the flame is then represented graphically, simply
by S_b being connected with M_b but not with M_c, and S_c
being connected with M_c, but not with M_b.

Having understood the all-pervading importance of
these conducting strings for the behavior of all more
highly organized animals, it is natural to seek for some
more detailed knowledge about their growth, their struc-
ture, and their function.

The smallest structural elements of which both animal
and vegetable organisms consist have for about a century
been called "cells." This means literally boxes—we
have a box under our house which we call a cellar. The
name appears less strange to us on knowing that those
structural elements which were first discovered by means
of the microscope happened to look like little boxes.
These were plant cells. It was, of course, soon found that
not all vegetable elements of structure are box-like. Some,
for example the long and thin flax fibers used for the
manufacture of linen, do not resemble a box. But the
name cell had already been adopted by the biologists as a
general name for elements of structure and was now applied
also to those elements to which it was not applicable in

its literal meaning. It was equally applied to the elements of structure in the vegetable and animal kingdom, and the whole living world was—and is—said by the biologists to consist of cells. Accordingly the strings, which serve as conductors for excitations in the bodies of higher animals, ought to be called cells,—for the sake of distinguishing them from other kinds of cells, perhaps nerve cells. Such, however, is not the case. The term nerve *cell* has come to mean, unfortunately, something different. We shall at once see what and why.

In its most undeveloped form an individual unit of nervous tissue is a small, almost spherical body (Figure 6,

a   b   c   d
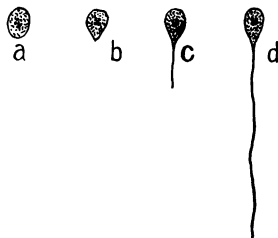
FIG. 6—Growth of a neuron.

a). As this body grows it becomes pointed in one or more places and sends out a string-like prolongation, which continues to increase in length (Figure 6, *b*, *c*, and *d*), so that it may become easily a hundred thousand times as long as it is thick, reaching a total length of several feet, whereas its thickness is always microscopical. The original little ball from which the string grew out, continues then to exist as a relatively thick swelling of the string. We must remember, however, that it only looks thus, that it did not originate as a swelling of the string. Being relatively bulky, it is not difficult to understand that this thickened part of the string should have attracted the interest of investigators before the exceedingly fine

string. When it was first the object of biological research, its belonging as a part to the long and fine fiber was overlooked. It was studied as an individual thing, and the name cell, generally applied to the elements of biological structure, was applied, instead of to the whole fiber with its swelling, to the swelling alone, which was called a nerve cell. So the inconsistent use of the word cell in its application to nervous tissue, referred to above, came about and is still almost universal.

In more recent years a new, unambiguous terminology has been adopted, which we shall use in the following. We shall call the whole structure, the fiber with its swelling, a *neuron*, the fiber without its swelling simply *fiber*, and the swelling alone a *ganglion cell*. The use of the word ganglion cell is explained thus: In nervous tissues gray looking masses are frequent which, on microscopical examination, reveal themselves as accumulations of swellings with the contiguous pieces of their fibers. It is as if we had a large number of ropes each having a knot somewhere and had taken all these knots in one of our hands. What we then have in our hand might be compared with the accumulation of swellings just mentioned. Such a mass of nervous tissue has long been called a *ganglion*. Now, it is a peculiar biological fact that these swellings of neurons are not found simply here and there in isolation, but that they are always found in groups, sometimes not very large, sometimes very bulky, —these very ganglions. Since the swellings of the neurons are always found in ganglions, they have been given the name of ganglion cells, which we shall adopt here.

Many are the forms in which the neurons present themselves. Figure 7 shows an assortment of them. The swelling may be at one of the ends as in the case of *a* and *c* of the figure, or away from either end as in the

case of *b*, *d*, and *e*. The long fiber may split into two
fibers as in *c*, or even into more. The swelling may
happen to occur just at the point of the division of the
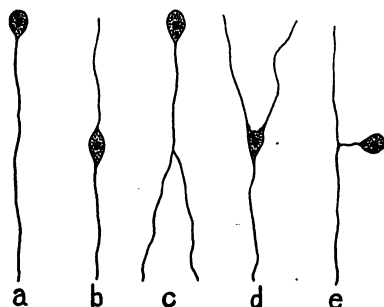
Fig. 7—Types of neurons.

string. In this case the neuron looks like *d*. The string
may in its course turn sideways, form a kind of loop,
and continue from the turning point in the original
direction. If now the swelling happens to be at the place
of the loop, the neuron must look like *e*. In all these
varieties of form we find the same structure, a string with
a swelling. Some years ago, when the interest of the
histologists was still in the main restricted to the ganglion
cell, various kinds of such cells were distinguished accord-
ing to the number of long fibers which they sent out, and
called unipolar (*a*), bipolar (*b*) and multipolar (*d*) cells.
Since the ganglion cell has ceased to be regarded as an
element of structure in the former sense, these distinctions
and names have practically lost their significance. The
neuron is essentially a string capable of conducting an
excitation from one end to the other. All structural and
functional properties are necessarily subservient to this
end of conduction.

Certain features of the neurons, which are not shown
in Figure 7, should still be mentioned.   We said that the
long fibers sometimes split into two fibers.   Another
breaking up of the fiber may occur in a manner similar
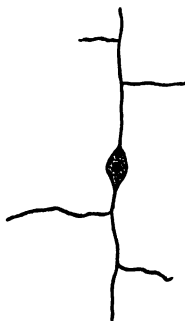
FIG. 8—Collaterals.

to the way in which a river takes up large tributaries.
Long fibers may enter the main fiber as in Figure 8.   The
tributaries, which most commonly form with the main
fiber angles of approximately ninety degrees, are called
collaterals.   But still another feature of the neurons is
to be mentioned.   Each ending of a nervous string looks
somewhat like the frayed-out end of a thread.   The end
breaks up into a large number of relatively short branches,
the so-called terminal arborization (Fig. 9, at *a*).   In
case the swelling of the neuron happens to be located at
one of the ends of a neuron, these small branches must
naturally come out of the swelling itself.   The neuron
then looks like Figure 9.   The branches proceeding from
the swelling are called dendrites; which is a Greek name
meaning about the same as the Latin name terminal
arborization, namely tree-like branchings.   In Figure 9
a neuron is represented whose main fiber is relatively

short, almost shorter than the dendrites. This shortness, however, is not the rule, but rather the exception; the main fiber, often also called the axis cylinder, usually greatly exceeds the dendrites in length.

There is frequently a difference in coloring between the parts of a neuron. The ganglion cell looks dark, the
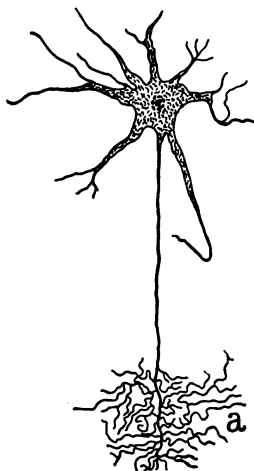
Fig. 9—Ganglion cell.

fibers lighter. This has given rise to the distinction of white and gray matter in the brain—gray matter taking its name from the presence of numerous dark ganglion cells among the fibers. The popular view, however, of the greater importance of the gray matter than of the white matter is a superstition.

The ganglion cells have a delicate interior structure, and even the fibers are not simple, but possess an interior structure, so that they may be said to consist of fibrils. About the functional significance of these inner divisions

of a neuron too little is at present definitely known. The question as to the function of the ganglion cell and the fibrous parts of the neuron must be answered at present in a manner very different from that which was customary fifty years ago. It was then often asserted that the ganglion cells were the residences of ideas, each little box the seat of one idea, so that the total mental capacity of a person might be determined by counting the number of his ganglion cells. It is now recognized that an idea can not be said to have its seat anywhere. The ganglion cells do not have any more direct relation to our mental life than the conducting strings. On the contrary, we shall see that we can fairly well understand our mental life without any reference to the ganglion cells. Their physiological significance is probably, in the main, only of the following two-fold kind. The ganglion cell is the point of vegetation, so to speak, from which all growth proceeds, and it is the storehouse from which the neuron in any emergency can quickly draw the means of subsistence. We have seen that the whole string of a neuron grows from a little sphere. This sphere continues to exist even after the neuron with all its ramifications has obtained its full development, and is then the ganglion cell of the neuron. If growth is necessary later, because a branch of the neuron has been cut off or otherwise destroyed, new growth proceeds from that point of the string which is farthest from, but still connected with the ganglion cell. On the other hand, if a conducting string is continually used for hours, changes in the appearance of its ganglion cell occur which probably indicate changes of a chemical nature, called by the physiologists signs of fatigue. It seems that the string, in order to serve continuously for a long time as conductor of an excitation, needs to be resupplied with certain chemicals, and that

these chemicals are kept in store for the string within the ganglion cell, which, because of its size, is less quickly exhausted than the string.   Whether the ganglion cell has any significance in addition to those functions just mentioned, seems doubtful.

THIRD LECTURE

Locomotion of the jelly-fish. Concerted action of all the divisions of the body and local responsiveness. Need of a gradation of connections differing in resistance. Corresponding points. Resistance dependent on length of conductors. Connections of non-corresponding points. Impossible manner of connecting the neuron arches. First improvement of manner of connection: One-way valves at the meeting points of neurons. Second improvement: The connections between the arches being themselves arches consisting of three neurons each.

W E have stated that the fundamental principle upon which the design,—the architecture, so to speak,—of the nervous system is based, is the following one. Each sensory point of the body is connected by a conducting string with a definite motor point of the body. The selection of a suitable motor point for connection is nature's proper business to which she has attended during a long process of evolution of the animal race. Every animal is born with fully developed connections of this kind, or, at least, with rudiments which by heredity are predetermined to grow into such connections during the individual's early life. If an animal is born without them, life is impossible.

However, it is easily seen that a nervous system of this extremely simple kind will need improvement as soon as

the animal race which possesses it makes progress from the most primitive to a somewhat higher organization of its bodily functions. Let us consider an example. A jelly-fish of the kind called acalepha still has an exceedingly low organization; yet it will make clear what we wish to understand. For locomotion it has a bell-shaped body, so that, on contraction of the bell, the whole body moves through the water in the direction of the closed end of the bell. When seen from the front the bell looks like Figure 10. On the periphery of the bell there are
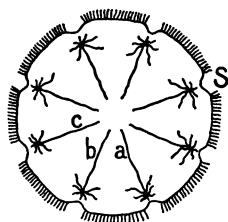
FIG. 10—Nervous system of a jelly-fish (acalepha).

eight points (one of which in the figure is marked S). From each of these points conducting fibers similar to the fully developed neurons in higher animals pass into the neighboring tissues, but not far enough to come into actual contact with the fibers radiating from any other point S. The purpose of these fibers is clear; they conduct any excitation occurring at any point of the rim with but slightly diminished effectiveness to all the tissues of that eighth-division, causing thus a uniform response of the whole division to any stimulus applied to any one of its points. In addition to these one fiber seems to pass from each S in the direction of the center of the bell. For what purpose? Obviously, to make it more certain that during the process of locomotion no division of the bell lags behind the others in contraction.

It is plain enough that no straight-way locomotion would result if, for example, the tissues on one side of the rim would contract when, having lagged behind, all the diametrically opposite tissues are still in expansion. This lagging behind, however, would frequently occur. To understand it readily, let us imagine the analogous case of eight leaky places on a water pipe. Suppose the frequency of the dropping at each place to be about the same, say, one drop a second. But even then we could not expect all the drops to fall simultaneously, eight further drops to fall again simultaneously after a second, and so on. The eight drops would fall in a quite irregular succession. Let us make the application to our case. The rhythmical contraction would be caused by the chemical constitution of the jelly-fish at the time in question, when perhaps no food has been taken for some time and locomotion thus has become necessary. The chemical constitution being about the same in all divisions, no division would have a frequency of periodic contraction differing much from that of any other division of the body. Nevertheless, the contractions would not occur in the eight divisions simultaneously any more than the falling of the eight drops spoken of above. But this simultaneity could be easily insured by connecting the eight divisions by conductors. Now, as soon as one of the divisions spontaneously begins to contract, this contraction causes an excitation in the nervous plexus of that division. This excitation is carried to all other divisions and at once all other divisions begin to contract.

This connection of all the divisions of the body would work beautifully if no other kind of locomotion were ever needed than straight-way locomotion in response to an internal stimulus, the chemical constitution of the body at the particular time, for example, some time after the

last taking of food. But frequently external stimuli act upon the body and require, not a straightforward loco-motion, but a change of direction as response. For example, the jelly-fish, while swimming, strikes a rock with one side of the bell. The jelly-fish then must change its direction. That division which touched the rock must contract more strongly than any other, especially than the diametrically opposite division, in order to bring about the change of direction. Without conduction, the predominance of the action of the one division touched would be certain. But with perfect conduction to all other divisions it would be equally certain that no such predominance of a local reaction, no local responsiveness to an external stimulus would be possible. Here is, then, the necessity of a compromise. And this compro-mise is effected by having the eight radial fibers not join in the center, but stop short before reaching each other. Thus undifferentiated tissues, tissues of high resistance, are interposed to weaken the excitation coming from one of the divisions to such an extent that only one division can react strongly to the external stimulus. All others react only weakly.

One must not think that for a concerted action of all divisions of the bell, like the action of straightforward locomotion, string-like conductors of differentiated tissue are indispensable. The various divisions of the rim of the bell might force each other into the same periodicity and, what is still more important for our present considera-tion, into the same phase of periodic contraction through the ordinary conductivity of the undifferentiated tissues. Whatever division is at any moment the first to contract, might send its excitation by means of conduction through the undifferentiated tissues to all the others and thus force the whole rim to contract at the same time. This

is the more possible when the periodic contraction of each particle is not the result of an external stimulus but, as we have seen, the result of a chemical constitution at any given time practically uniform throughout the whole body. The stimulus coming from one division, not having to cause, but only to hasten in all the others the contraction which would have occurred a little later anyway, need be only weak. Nevertheless, the question remains if it would not be too weak if it had to pass wholly through undifferentiated tissue. Nature, therefore, must make the radiating conductors just long enough to meet this condition of reducing the resistance just enough for concerted action; but not the least longer, for every increase of their length is equivalent to cutting down the local responsiveness without which the animal could not survive. We understand thus why the radiating fibers do not join in the center.

It is interesting to note that compromising, which is the very foundation of all social life of animals, of all social institutions of mankind, is found to be an essential function in the individual life of any one of the very lowest animals which possess a nervous system. The unity of all organized nature, which is the fundamental concept of modern biology, is exemplified by this role played in any life, low or high, by compromises. Two conflicting conditions seem to make life impossible. But the problem would be hopeless only if a complete denial of the demands of either the one or the other were insisted on. On the one hand, *concerted action* calls for the most perfect conduction from any division of the rim of the bell to all the others. On the other hand, *local responsiveness* calls for the interposition of high resistances between the diametrically opposite divisions of the rim. The compromise must then consist in this, that all the divisions are

connected by conductors, but in such a way that conduction from one point of the rim to opposite points is by the properties of the conducting medium itself more resisted than conduction to neighboring points. Nature has, as we saw, solved the problem by stopping the differentiated radiating conductors as far short of the center as the condition of local responsiveness requires, leaving in the center enough undifferentiated tissue interposed to meet this requirement. Another way of fulfilling the condition of varying resistance is by resorting to the *length* of the differentiated conductors without interposing any undifferentiated tissue. There can be no doubt that the length of a nervous conductor determines its resistance as the length of telegraph and telephone wires determines their resistances. The longer the conducting string, the greater its resistance. Nature has solved the problem in this way in another kind of jelly-fish, called hydromedusa. Here all the points of the rim are connected by differentiated conductors forming a ring, as shown in Figure 11.
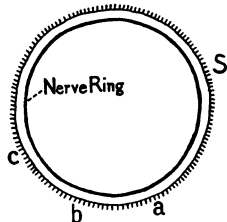
Fig. 11—Nervous system of a jelly-fish (hydromedusa).

If any division of the rim contracts, the excitation is by this ring conducted to all other divisions. But the excitation reaching opposite divisions of the rim is much weaker than that which reaches neighboring ones, in accordance with the varying length of the conductor. This difference in the intensity of the conducted excitation does no harm

in the case of ordinary, straightforward locomotion. The rhythmical contraction is in this activity the result of the chemical constitution of the body which, perhaps, has been the result of lacking food for some time. This chemical state differs but slightly in the various parts of the body. The different divisions of the rim, therefore, would contract and expand in almost the same periodicity anyway. A very slight excitation conducted from elsewhere is then sufficient to hurry up any division which without this excitation would lag behind. But when a stimulus acts *from without* on any point of the rim, only those divisions are caused *to respond strongly* to the stimulus which are in the neighborhood of the stimulus. The other divisions of the rim, receiving *a weaker and weaker excitation* the longer the piece of the rim over which the excitation has to travel, are considerably affected only in the neighborhood of the point of stimulation. The divisions opposite this point remain practically unaffected by the stimulus.

Let us glance back again at Figure 10. We said that (1) the radiating fibers help to prevent the lagging behind of any division in the ordinary activity of locomotion. The figure makes it clear that any excitation is more effectively conducted between any divisions by the help of these fibers than it could be conducted through the undifferentiated tissues. (2) The local responsiveness is retained by the radiating fibers stopping short before reaching the center of the bell. For example, if S is stimulated by an external influence, the excitation is carried also to a, b, and c, but more weakly to a and b and very much more weakly still to c. In order to reach c the excitation has to pass from the radiating fiber S to the radiating fiber c over a rather long step of undifferentiated tissue. Undifferentiated tissue has a much higher

resistance than nervous tissue. Consequently, the excitation reaching the points, *a*, *b*, and *c*, is more and more weakened, and no interference with the local responsiveness at the point *S* can appear. If the radiating fibres did unite at the center of the bell, *a*, *b*, and *c* would all be equally excited. The problem of universal connection of all parts of the body by conductors of low resistance, combined with undisturbed local responsiveness, can therefore be solved architecturally in more than one way. Figures 10 and 11 represent two solutions of the problem, both found in nature. But the solution of Figure 11 is the more perfect one, because the universal communication through conductors is more perfect, while local responsiveness is as satisfactorily retained as in the other case.

The example of the jelly-fish has taught us that one kind of nervous connections within the animal body is not sufficient. There must be many kinds,—or rather, there must be a gradation of connections differing in the resistance offered by the conductor in the various cases. If it is desirable for an animal's well-being that an excitation occurring at a certain point, say *A*, be followed most readily by a contraction at the point *a*, the points *A* and *a* must be connected by a conductor of small resistance. Let us call those points which are thus connected *corresponding points*, in order to have a brief term by which we may refer to them. If, as in the case of a jelly-fish, these corresponding points *A* and *a* are practically identical, the conduction is a self-evident fact even without any special conductors. If, as in the case of the moth, *A* is an eye and *a* the muscles of a wing, the conduction between the corresponding points must be mediated by a nervous string, or chain of nervous strings, of the shortest length possible under the anatomical

conditions. But all—or at least some—of the other
(non-corresponding) contractile points of the body must
also be in some way connected with the point A. Other-
wise, no concerted action would be possible. The jelly-
fish would, for example, be scarcely capable of swimming
straight ahead; the moth would hardly be able to alight
on a twig or leaf which happens to impress itself on the
moth's eye and towards which the moth must act, not
only with its wings, but also with its legs. These further
connections with the point A, however, in order to leave
the connection A-a in its proper functional order, must
have a higher resistance,—as we have seen, must be
longer than A-a.

In higher animals, whose tissues are all differentiated
to perform special functions, the nervous connections are
practically all connections between *sensory* and *motor*
points, that is, between points of the body which are by
differentiation specially sensitive to particular physical
or chemical influences, and points which are of differenti-
ated contractile tissue. It is true that nerve fibers are
also found to end in tissues which are not contractile; in
glands, for example. However, these cases are the
minority, and may be left out of the discussion here,
since we are especially and directly interested in behavior
only, which depends, of course, on the function of con-
tractile tissues, of muscles. We have represented in
Figure 5 the short—or direct, as we may say—connections
between corresponding sensory and motor points in the
shape of arches. We must now find a way of representing
graphically those nervous conductors which lead from
each sensory point to those motor points which are not
corresponding. These conductors must be, as we have
found, longer than the conductors directly connecting
corresponding points. It is clear, then, that we could *not*

represent the conductors connecting non-corresponding points as they are represented in Figure 12. This figure is shown here merely because some books, treating these problems somewhat superficially, actually give figures like this as an example of how nervous connections are constructed. Let us agree that any straight line which has no cross-connecting point between its ends, shall always represent a standard length, and also, unless anything is said expressly to the contrary, a unit of resistance Such lines as $S_a^1 M_b^1$, which has a crook inserted between its straight ends, are included under this definition. This line is drawn so as to indicate that it is not in contact with $S_b^1 M_a^1$; for this purpose the method of drawing which is generally used by electrical engineers to indicate crossed, but mutually insulated wiring, has been adopted. A glance at the Figure 12 shows that the conductor
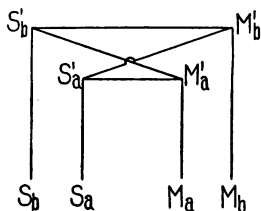
FIG. 12—Impossible manner of connection.

$S_b S_b^1 M_a^1 M_a$ connecting the non-corresponding points S_b and M_a has not a greater resistance than the conductor $S_b S_b^1 M_b^1 M_b$, since both are made up of three standard lengths, although our requirement is that it shall have a greater resistance. We must look for a different kind of graphic representation to suit our needs.

Neurology, that is, the anatomy and physiology of the nervous system as it actually exists and functions in animals and in man, teaches us an important fact which we ought to represent in any diagram of nervous connec-

tions. It has been found that the same two points (one sensory and one motor) are almost generally connected in several ways, by shorter and also by longer conductors. For example, if pain is caused in a dog's foot and the foot is withdrawn, the nervous excitation may travel from the foot to the spinal cord and thence to the muscles moving the foot. Or, it may travel from the spinal cord farther on to the dog's brain, thence back to the spinal cord and now only to the muscles. If we combine this requirement of a two- (or many-) fold connection of greater and lesser length between corresponding points with our previous requirement that the connections of non-corresponding points shall be longer than the (direct) connections of corresponding points, the diagram of Figure 13 readily suggests itself. We draw four conducting
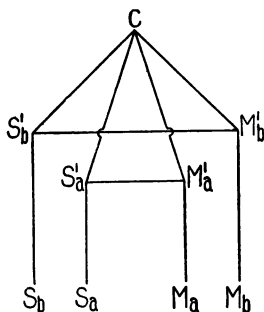
Fɪɢ. 13—Imperfect manner of connection.

strings from S_a^1, S_b^1, M_a^1, and M_b^1 and unite them in a central point which we may call C. All our requirements are then fulfilled. We can travel from S_a to the corresponding point M_a over a longer route by C (four standard lengths), or over a shorter route (three standard lengths) avoiding C; and we can travel from S_a to the non-corresponding point M_b only over a longer route

$S_aS_a^1CM_b^1M_b$ of four standard lengths.   The same holds good for starting from the sensory point S_b.

Nevertheless, this diagram of Figure 13 is not yet quite satisfactory, but must be perfected in at least two ways.   First, an excitation starting from one sensory point, for example S_a in Figure 13, can not only pass, over various routes, as we have seen, into the conductors $M_a^1M_a$ and $M_b^1M_b$, but also from C into the conductor CS_b^1 and from M_b^1 into the conductor $M_b^1S_b^1$, and then further from S_b^1 into the conductor $S_b^1S_b$.   Thus the excitation, whose ultimate end is naturally the causation of contraction in contractile tissues, would be only partly used for this end; a large part would be wasted by going into sensory points where, in animals with highly differentiated tissues, no contraction is possible.   We must, therefore, draw our diagram in such a manner that the passing of any excitation into a sensory point is excluded.   One way of doing this is by drawing each conductor, each neuron, in the shape of an arrow-like rod as shown in Figure 14.   We
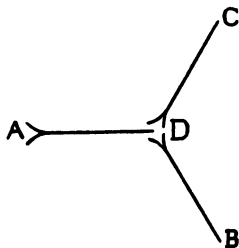
Fig. 14.—One-way valves.

can then easily agree and remember that the point of any arrow shall mean that no excitation can enter here from any other neuron whereas the split end shall mean that an excitation can enter here, but can not pass out.   Any point like the point D in Figure 14, where several neurons

meet, indicates then, according to the manner of drawing, that an excitation may pass from AD into either DB or DC, but that no excitation can pass from either CD or BD into DA. It is as if a double one-way valve located at D allowed the flow of a fluid in one direction, but prevented the flow in the opposite direction. We must ask, of course, if the facts known to neurology permit the assumption that the meeting point of two or more neurons functions like a one-way valve.

Experiments have proved, it is true, that an excitation may travel to the other end of a neuron, in whatever end it is called into existence by the application of an artificial stimulus. But with respect to the propagation from neuron to neuron, neurological experiment and observation seem to agree with the view expressed in the diagram of Figure 14. Everybody knows that our feet are connected with our eyes as well as with our ears, and, of course, also with other sense organs. If a strange and ferocious looking animal suddenly appears to any ordinary person's eye while he is sitting, he jumps up and starts running. If he is sitting in the theater, and suddenly the fearful cry "fire" strikes his ear, he also jumps up and starts running. That is, the muscles moving his feet are connected with his eye as well as with his ear. But his eye and ear are connected with many other muscles too; else, for example, he would not turn his head in response to a friend's call or eat what is placed before him on the dinner table. Now, neurologists have discovered in the brain the so-called motor region of the foot. If this region of the brain is artificially stimulated, the muscles belonging to the foot contract and move the foot. Suppose the excitation caused by the stimulus could proceed, not only in the direction of the motor organs most closely connected, but also in the direction of sense organs, for

example, the eye and ear. The eye and the ear are very closely connected with the motor region of the foot in the brain; they are also very closely connected with many other muscles of the body. It should then have been observed that in response to the artificial stimulation mentioned not only the foot, but many parts of the body moved. If such were the case, the neurologists would never have discovered the motor region of the foot. This very discovery means that they observed an exclusive reaction of the foot to stimulation of this region of the brain. We are justified, then, in our assumption of a one-way propagation of an excitation from neuron to neuron. We need not assert, dogmatically, that no other interpretation of the experimental facts is possible. But the assumption of one-way conduction from neuron to neuron, always *away from sensory points and toward motor points*, is simple enough and does not contradict any known facts. Besides, the anatomical connection between neurons is of such a wonderfully elaborate kind, that it seems quite probable that the meeting points have a peculiar function, actually perhaps much more complicated than the simple function of a one-way valve. The neurons do not run into each other like wires soldered together, but their end branches are interwoven. The purpose of this method of connection is not known, but it surely involves more than a mere making one out of two.

We said above, with reference to Figure 13, that the diagram of that figure needs additional features in order to make it more perfect. First, then, we shall draw the meeting point of several neurons in the manner of Figure 14, indicating for each neuron the direction *from* a sensory point and the direction *towards* a motor point. A second improvement is necessary because the diagram of Figure

13 does not permit the representation of a *series* of motor
points which can all be reached from one definite sensory
point, but only over conductors each differing in resistance
from all others.   These conductors, in order to have each
its special resistance, must all differ in length.   At the
same time, each motor point may have its own sensory
point with which it is connected by a conductor of mini-
mum length.   The whole case, then, is somewhat com-
parable to that of the jelly-fish in Figure 11, where all
contracting points can be reached from any point stimu-
lated, but only over paths differing in resistance.   The
insufficiency of the diagram of Figure 13 becomes clear
if we enlarge it by connecting (in Figure 15) in the same
way not only two, but three pairs of corresponding points.
In Figure 15 an excitation can travel from S_a to M_a over a
path of three standard lengths.   From S_a to M_b an
excitation can travel only by C over a path of four standard
lengths.   We have, therefore, a difference of resistance.
But from S_a to M_c there is again a path of four lengths,
so that there is no difference of resistance between the
path leading to M_b and that leading to M_c.   In order to
represent a gradation of resistances we need a diagram
differing from that of Figure 15.   *Instead of a point C,* we
have to introduce a *line,* as shown in the *horizontal lines*
of Figure 16, representing each a neuron of standard
length and resistance.   In other words, the connections
between the arches must themselves be arches consisting
of three (or more) neurons each.

In Figure 16 three colors have been used in order to
facilitate the recognition of the direction from sensory
points to motor points.   All green conductors in the
figure can be traveled only in the direction from below
up, all red ones only in the direction from above down, all
violet ones only in the direction from the left to the right.

We can travel, in Figure 16, from S_a to M_a over S_a^1 and

Fig. 16—Nervous architecture: Neuron arches and their possible connections.
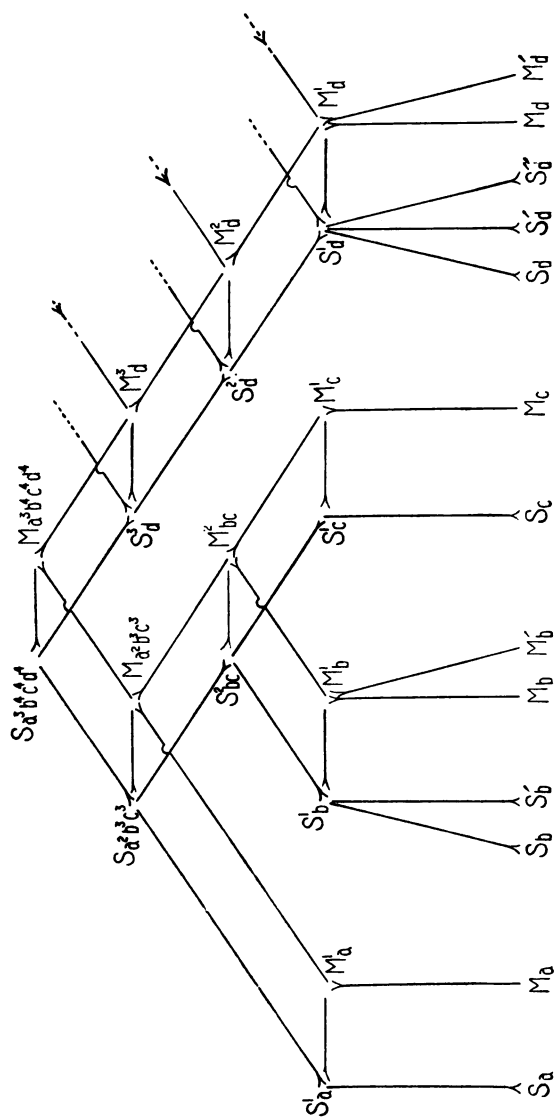
Fig. 17—Possible modification of details in nervous architecture.

M_a^1 directly, taking a path of *three* lengths. From S_a to M_b the shortest path is over S_a^1, S_{ab}^2, M_{ab}^2, and M_b^1. This path has a total length of *five* units, two more than from S_a to M_a.

From S_a to M_c the shortest path is over S_a^1, S_{ab}^2, S_{abc}^3, M_{abc}^3, M_{bc}^2, M_c^1. This path has a total length of *seven* units. At the same time the corresponding points S_b and
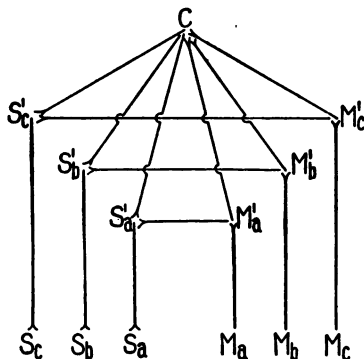
Fig. 15—Imperfect manner of connection.

M_b are connected by a short path $(S_b,\ S_b^1,\ M_b^1,\ M_b)$ of three units, the corresponding points S_c and M_c also by a short path $(S_c,\ S_c^1,\ M_c^1,\ M_c)$ of three units. This diagram, therefore, exactly fulfils the condition of *universal connection* without interference with *local responsiveness* of an animal's body. We shall have to investigate whether a nervous system like the one represented in Figure 16 is sufficient for the needs of all the higher and the very highest animals,—whether we have a right to assume that even the nervous system of man is built essentially (apart from simplification and elaboration of the details) on the design of this figure. We have, of course, the right to assume this, if we can convince ourselves that all the actual functions of the nervous system in man's body are thus made comprehensible.

FOURTH LECTURE.

Reflex arches. Their peripheral and central points. Central sensory points and central motor points. Central points of a lower and higher order. Lettering of diagrams explained. Central sensory and central motor neurons. Reflex and instinct. Instinct a selecting and collecting agent. Overflow of a strong sensori-motor discharge into the most closely connected arches. The source of motor power different from the signal for its expenditure. What a nervous excitation can be likened to. Signaling by rods and levers or by pneumatic tubes. Velocity of signal very great, but not infinite; not dependent on intensity. A neuron likened to an electric storage element. A simple picture of a nervous process needed for our imagination of nervous function.

THE design of Figure 16 allows infinitely many modifications and elaborations without deviating from the general principle upon which it is based. This principle may be stated in the following words. Each *sensory* and each *motor point* of the body contains one of the ends of a neuron which, accordingly, may be called either a *sensory neuron* or a *motor neuron*. The other ends of each pair of a sensory and a motor neuron are connected by what may be called a *connecting neuron*. The whole, represented in the figure in the shape of an arch, for example, S_a S_a^1 M_a^1 M_a, may be called a *reflex arch*. Each reflex arch is composed of at least one sensory, one motor, and one connecting neuron.

The number of neurons, however, forming a reflex arch, need not be limited. Any line in our diagram, the sensory neuron $S_a S_a^1$, for example, might actually be a chain composed of several neurons. But for our present purpose of constructing a simple diagram typical of the design of the nervous system, this possibility need not be dwelt upon. Further, several sensory neurons may run together into a common meeting point, as $S_d S_d^1$, $S_d' S_d^1$, and $S_d'' S_d^1$ in Figure 17. And the same may be true for several motor neurons, as $M_b^1 M_b$ and $M_b^1 M_b'$ in the same figure. Nevertheless we may say, since to generalize is our present business, that each reflex arch is composed of a sensory, a connecting, and a motor neuron. We must say a word, however, as to why we have called these arches reflex arches. The term reflex has been a physiological term for centuries. The early physiologists used it to signify the great quickness and definiteness with which certain actions occur compared with the slowness and variability of others. To take an example from human life, if we bring the tip of the finger suddenly close to the eye of a stranger sitting opposite us in the street car, he surely and most quickly shuts his eye. Such an action seems to deserve the name of reflex action. It occurs, or seems to occur, as promptly and definitely as our own features are *reflected* back towards us when we look at ourselves in a mirror. But if we ask the stranger to lend us a dollar, he puts his hand in his pocket—if he does it at all—only after a good deal of hesitation, of delay. This does not seem to deserve the name of reflex action. Modern physiology, however, has gradually put less and less emphasis on the quickness of the response in the case of so-called reflexes, and more on its definiteness. For example, in such reflexes as coughing, or vomiting, or intestinal action there is not necessarily any great

quickness, but a great definiteness of response. Now, we may most naturally regard the definiteness as being determined by the fact that of the innumerable motor outlets of the excitation just one is superior to all others in being reached over the shortest path, offering the least resistance. Such a path may be represented by one of the arches of our diagram, since each arch assigns to each sensory point just one motor outlet of specially low resistance. We may, then, call these arches reflex arches, but we must remember that by giving them this name nothing is proved or disproved, nothing is made clearer than it would be otherwise,—we have merely referred to a traditional physiological term when occasion seemed to offer.

Each reflex arch contains four points. We may give them different names by calling them peripheral points (S_a and M_a, for example) and central points (S_a^1 and M_a^1, for example). These terms "peripheral" and "central" must not, however, be understood literally. The peripheral points are not always located on the anatomical periphery of the body, the skin;— some sensory points are located in the skin and some in the inner parts of the body, whereas the motor points, in muscle fibers, are necessarily without exception beneath the skin. Neither are the central points always located in a central part of the body. The words peripheral and central are used in a loose sense, as a telephone station in a city is called central, although it may be located far from the centre of the city. We may then speak, not only of a peripheral sensory point and a peripheral motor point, but also of a central sensory point (S_a^1) and a central motor point (M_a^1). This does not signify that these points are in a strict sense sensory and motor, but merely that one of them (S_a^1) is nearer to a sensory than to a motor point of the body, and the other (M_a^1) is nearer to a motor than to a sensory

point of the body. It is easily seen, then, that in the diagrams of our figures several central sensory points are collected, so to speak, by neurons (central sensory neurons) into a central sensory point of a higher order. For example, S_a^1 and S_b^1 are collected into S_{ab}^2. This is done in a manner not different from that in which the peripheral sensory points S_b and S_b' are collected into S_b^1. The central motor points are also collected (by central motor neurons) into central motor points of a higher order, for example, M_a^1 and M_b^1 into M_{ab}^2. The same principle of design is then applied again. From the central sensory point to the central motor point of the second order there are several paths — a direct one $(S_{ab}^2 M_{ab}^2)$ and more indirect ones, for example $S_{ab}^2 \ S_{abc}^3 \ M_{abc}^3 \ M_{ab}^2$. We find there the same manner of connection which we found for S_a^1 and M_a^1, which too had a direct and a less direct path of communication. The whole design, complicated as it looks at first, is really built upon a very simple principle, applied consecutively in regular order, — the principle, that from a sensory to its corresponding motor point there are always direct and less direct paths of communication, and that the less direct paths serve the purpose of connecting each sensory-motor system of conductors with other systems of a similar kind by the aid of a common path, always represented graphically by a horizontal line.

The letters and digits added below or above each S or M very simply indicate the peripheral points with which the point in question is most directly connected (for example, S_{bcd}^3 with S_b, S_b', S_c, S_d, S_d', and S_d'') and the total number of unit conductors making up any such connection (for example, three neurons for S_{bcd}^3, two for S_{ab}^2). Where the number of units differs for different peripheral points, the digit is added, not to S or M

but to a, b, c, etc., as the case demands. For example, in the diagram of Figure 17, $S_a{}^2{}_b{}^3{}_c{}^3$ indicates that the distance from this point to S_a is one of only two unit lengths, but to S_b of three lengths, and to S_c also of three lengths.

We spoke of the physiological term reflex. We may use this opportunity to refer now to another traditional term, that of *instinct*. When one observes that a bird, without having been taught by experience or by other birds, builds a nest before laying any eggs, one usually says that the bird has done this instinctively. Here again there is a certain promptness and definiteness of action as in the case of a reflex action, but promptness and definiteness of a different kind. Let us try to make clear of what kind. The bird does not many times lay eggs which are doomed to perish because there is no place to receive them, until some time it happens to prepare a nest before the act of laying. But before the first egg is laid, the nest is prepared in quite a definite way, well suited for the hatching of the young. Of course, there are certain physiological processes in the bird's body which, previous to laying, cause excitations in definite sensory neurons, and these excitations are conducted to the motor neurons controlling the act of building. Why are they conducted just here and not to any other motor neurons? Obviously, because of short connections, of relatively small resistance, between these motor and these sensory neurons. But the figure of speech of a "mirror-like reflection" is not applicable. We cannot comprehend an instinctive activity by simply referring to a reflex arch,—it is too complex and variable for that. It is definite only in the sense that it occurs at a time when innumerable stimuli acting on innumerable reflex arches make us regard almost any other kind of muscular activity as just as probable as the one which actually occurs, some of them stimuli

without the presence of which the act of building would not have occurred, some, however, quite irrelevant to the act of building. For example, a suitable site for the nest and suitable building material must impress themselves upon the eyes. But even this site and this material might have called out innumerable other responses just as well. The *specific excitation* of the instinct, caused by the internal physiological stimulus aforementioned, therefore cannot be the all-sufficient cause of the action, but must be rather of the nature of a *selecting and collecting agent*, weakening and rejecting those excitations whose presence is unnecessary, or whose reflex responses would interfere with the instinctive action, strengthening and uniting all those excitations whose presence is necessary for the performance of the instinctive action. Let us now try to comprehend the effect of the specific excitation of the instinct by the application of the diagram of Figure 17.

Let S_d S_d^1 represent all those sensory neurons any excitation of which is likely to interfere, if the corresponding reflex responses are allowed, with the performance of the instinctive activity. To illustrate this by a concrete example, think of flying. It is clear that any long continued flight would make nest building an impossibility, even though short flights are with many birds an essential part of the building activity. Here a selection is needed, excluding, on the whole, such motor responses as flight. Let, further, S_b S_b^1 and S_c S_c^1 represent all those sensory neurons whose excitation is necessary for the instinctive activity. For example, the bird's eyes must see the site and the material. Here a collection is needed, including in the activity the motor responses upon such things as a building site and building material. Let S_a S_a^1 represent the sensory neuron whose excitation is what we

called the specific excitation of the instinct, which selects
and collects among the nervous processes coming from the
other sensory points. How, then, can we comprehend
the influence of the excitation coming from S_a upon the
motor activities at the points M_b, M_c, and M_d? Obviously,
the excitation coming from S_d must be prevented from
reaching the corresponding motor point M_d. The excita-
tions coming from S_b and from S_c, however, must not be
prevented from reaching their corresponding motor points
M_b and M_c, but their effectiveness must be enhanced as
much as possible:—the bird must not do any other
things, but pick up building material and drop it at the
site of the nest in the proper manner leading to the forma-
tion of a nest.

It seems clear that this acting as a *selecting and collecting
agent* as we said above, can be best understood by assum-
ing that the excitation coming from S_a, being so *strong*
that the direct discharge over S_a^1 and M_a^1 into M_a overflows
the channel of its reflex arch, partly travels *upwards* from
the point S_a^1. Because of the connections naturally
existing it can reach equally well *both* M_b^1 and M_c^1
over shorter paths than it could reach any other points
(e. g., M_d^1) leading towards motor organs. Thus it en-
hances the muscular contractions at both the motor points
M_b and M_c. The connections of the generalized design
of Figure 16, however, do not fulfil this condition. They
would favor M_b over M_c. The connections representing
the instinct must be like those of Figure 17, which is
derived from Figure 16, in the main by simply omitting
certain conductors, as a comparison of the two figures
immediately reveals. If we travel in Figure 17 from S_a
to any motor point other than M_a over the *shortest* pos-
sible route, we can travel only over S_a^1, $S_a{}^2{}_b{}^3{}_c{}^3$, and
$M_a{}^2{}_b{}^3{}_c{}^3$ to either M_b or M_b' or M_c. In this case the entire

path from the sensory to the motor points has a total length of six units. Had we traveled from $S_a{}^2{}_b{}^3{}_c{}^3$ up to $S_a{}^3{}_b{}^4{}_c{}^4{}_d{}^4$ and $M_a{}^3{}_b{}^4{}_c{}^4{}_d{}^4$ and thence to any other motor point, for example, to M'_d, the path would have had a total length of at least eight units. The control by the strong and overflowing excitation from S_a of the function of the motor points M_b and M_c, the *collecting* agency of the instinct, is thus graphically represented by the relative shortness of the connecting conductors. On the other hand, the inhibiting influence of the excitation coming from S_a upon the function of the reflex arch $S_d M_d$ is graphically represented by the bare existence of a connection by means of the connecting neuron $S_a{}^3{}_b{}^4{}_c{}^4{}_d{}^4$ $M_a{}^3{}_b{}^4{}_c{}^4{}_d{}^4$. This connection must make it possible for the nervous process coming from S_a to capture, as it were, the nervous process coming from S_d, thus preventing it from reaching M_d. But we are still far from understanding this inhibiting, selecting influence. The diagram of connection by conductors in Figure 17 is only one of the assumptions necessary for the explanation of instinctive activity. We shall return to this problem in the following lecture. It is necessary that we investigate first what other assumptions we have to make to understand theoretically what nervous activity means.

We have already compared the nervous system with a signal system, a telephone system by means of which messages may be sent. We must understand more clearly what kind of a signal system it is. It is important, however, that we keep clearly before our mind that it is only a system for signaling, not a system for the transmission of power. It can not be compared, for example, with the electric light and power circuit of a city, furnishing to many houses in many streets power which is generated in a central station. An animal's muscular power does not take

its source in the nervous conductors attached to the muscles. The power is derived from the digested food through mediation of the blood circulation. The power is thus stored in the muscles, ready to be expended at the proper signal. The nervous excitation is the signal, the message that the power should be expended. To be sure, the amount of power expended is not altogether independent of the force of the signal, of the intensity of the message received. But that the power is not derived from the messenger is clear from the fact that when a muscle is exhausted, no nervous excitation can make it contract.

What, then, is the excitation which is propagated through a nervous conductor in order to serve as a signal to a muscle fiber. This, however, is not really a good question. What it is, in other words, what name is to be applied to it, is directly of little significance. What it can be likened to, is the question which we should rather ask. What thing with which we are familiar in the ordinary functions of life, acts like a nervous conductor through which an excitation is taking its path?

Fifty years ago, when a master desired to call his servant, he rang the bell in the servant's room by means of a rigid wire connection extending over pivoted angles from his own to the other room. Now, let nobody think that this comparison is absurd from the start. Everybody knows, of course, that there are no wires and pivots in any nervous system. But we have already emphasized that it is of minor importance what there is, that we are concerned rather with what goes on there. Does the signaling going on in the nervous system permit comparison with the signaling done by pulling a bell cord? Now, it does not. If for no other reason, for this, that the bell attached to a perfectly rigid wire or rod begins to ring the very moment the other end is pulled. But when an excitation is

caused at one end of a nervous conductor, it is not at the same moment also at the other end, but measurably later,—the later, the greater the distance between the two points. We must look, therefore, for a different comparison.

Everybody knows the grand musical instrument in which the player, pressing down the keys, opens at considerable distances from the keyboard the valves which make the various sources of sound speak. In the pipe organ too the messages were sent until comparatively recent times from the keys to the valves by means of rigid connections, as from the master's room to the bell in the servant's room. No delay is permissible in the response of the pipes to the touch of the fingers on the keys. The rigid connection, therefore, seemed to be the only possible one. Nevertheless, the modern organ has been freed of all rigid connections. A narrow tube runs from the key to the pipe valve. The motion of the key opens a tiny auxiliary valve which admits compressed air from the main reservoir to the tube just mentioned. At the other end of the tube is a tiny bellows which is raised by the compressed air and thus operates the pipe valve. Now, what use can we make of our knowledge of this familiar mechanism? We shall see at once that we can thus elucidate certain fundamental facts of the function of the nervous system. The pneumatic mechanism does not operate the pipe valve at the very moment when the key is moved by the finger, but at a measurably later time,—the later, the longer the connecting tube. However, the time interval is short enough to be negligible in musical practise, provided the connecting tube is not extraordinarily long. The time interval is practically independent of the density of the compressed air in the reservoir. It is simply proportional to the length of the

tube, provided the tube is plain and does not contain in its course any additional mechanisms. The corresponding facts are found in the function of the nervous system. The muscle fiber does not contract at the very moment when the sensory point is excited, but some time later,— the later, the longer the nervous path connecting the sensory and the motor point. Yet, the time interval is, in the case of a reflex, quite negligible according to our standards of time in ordinary life,—so much so, that for centuries, until modern methods of measuring exceedingly short time intervals were invented, the time was regarded as absolutely zero, that is, the response was indeed believed to occur at the very moment when the sensory point was excited. It has further been shown by experiment, that the contracting of the muscle fiber does not occur any sooner if the excitation of the sensory point is made stronger.

With all this, however, we do not want to suggest that a neuron is a narrow tube through which a fluid is pressed. We have emphasized before that we are merely searching for familiar functions with which we may compare the nervous functions in order to assist our power of imagination and reflection. Let us use this opportunity to tell briefly what physical processes have actually been found by the neurologists to go on in the nervous conductors. Whenever anything of the nature of an excitation occurs in a neuron, an electrical phenomenon is observed. But it is generally admitted that this electrical phenomenon is not the excitation itself. There is no such thing as an electrical insulation surrounding a neuron, which would enable an electrical current to pass along a neuron. And further, the velocity with which the excitation is conducted is almost infinitely small when compared with the velocity of electricity in its conductor.

During the time a nervous excitation is conducted one way and back through an elephant or other large animal, electricity can circle the globe. The electrical phenomenon must be, therefore, a purely accidental accompaniment of the conduction of an excitation. It is highly probable that the conduction of the excitation is a process of a chemical nature. The substance of a neuron, consisting of highly unstable organic compounds, must be well adapted to the conduction of chemical changes. It is also well known that the conduction of chemical changes frequently involves, as by-products, so to speak, electrical phenomena. Indeed these electrical phenomena accompanying the conduction of chemical changes have been used technically and have become of the greatest industrial importance in the so-called accumulators or electrical storage batteries. An accumulator is essentially a conducting fluid on the sides of which there are two related, yet different chemical substances, most commonly lead compounds. One of these substances has a tendency to take up a certain more elementary substance; the other has a tendency to give off this same elementary substance. The same elementary substance is one of the components of the conducting fluid. What happens is this: A stream of elementary substance flows—or, whatever it may actually do, is imagined to flow — from one end of the conductor to the other, and this flow, the wandering of molecules or ions, as it is usually called, is accompanied by an electrical phenomenon. We are, then, probably justified in regarding the conduction of an excitation through a neuron as, not identical with, but at least analogous to the wandering of ions through the conducting fluid—the electrolyte, to use the technical term—of a storage battery.

Concerning the chemical and physical properties of the neurons hardly anything further is known which

could make the function of these wonderful structures clearer.   It is not especially remarkable that the chemistry of the neuron, although it has attracted in recent years the attention of investigators, has made little progress. We need only remember that the neuron is a microscopic structure, and that for a chemical analysis a more than microscopic quantity of the substance to be analyzed is required, and we understand why no one yet knows how the excitation actually wanders from one end of a neuron to the other end and thence to the other neurons.   For the very reason that the chemistry of the neurons is a thing of the future, we may picture to our own imagination the processes going on in the neurons in terms not necessarily chemical, in any kind of terms with which we are familiar and which enable us to understand the function of the nervous system as being *a complex of a few* — as few as possible — *simple functions*.   We have pictured it as a process like the one going on in a connecting tube of a pneumatic organ.   Let us now draw further conclusions from this assumption.

FIFTH LECTURE

Advantage of comparing the nervous process with a process of streaming. Analogy of the jet-pump. The whole nervous system permeated by any nervous process, but not with uniform intensity. Suction at motor points; openings made at sensory points. Velocity of the relief of tension. Conditions of the intensity of streaming at any definite point of the system. Exhaustion. Resistance increasing with, and even more rapidly than, the flux. Overflow not identical with universal permeation. The selective function of an instinct explained by the principle of deflection, the collective by that of overflow.

SPEAKING of the fundamental facts to which one customarily refers by the term instinct, we showed (page 53 and Figure 17) that one of them consists in the capturing of the nervous process going on in one reflex arch $(S_d\,M_d)$ by the nervous process going on in another reflex arch $(S_a\,M_a)$, in such a manner that the former process, coming from S_d, could not reach its normal end in the motor point M_d. Does it help us to understand this possibility of one nervous process capturing another, deflecting it from its normal course, if we compare nervous processes with the conducting mechanism of a pneumatic organ? It does indeed, although no such capturing takes place in an organ. The little bellows operating a pipe valve is filled by air *streaming* through the connecting tube. Now, it is one of the most interesting facts of

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physics that *a stream can deflect another stream* with which it is in contact. This is equally true for gaseous and liquid substances, there being in this respect no fundamental difference between them. We are all familiar with many kinds of apparatus using this principle of deflection. Think of the various sprayers for spraying perfumes or substances for inhalation, or for spraying with insecticides the vegetables growing in the fields. In these sprayers the liquid to be distributed is usually taken—deflected, if we wish to say so—from the vessel in which it is contained, by a stream of air. Or think of the jet-pump, draining, perhaps, the cellar under our house, or exhausting air from a glass bell in our laboratory. It is not necessary for us here to discuss these phenomena from the standpoint of theoretical physics, to explain them mathematically. It is sufficient to mention them as familiar facts. In all these cases it is irrelevant, of course, whether the deflected stream really streams originally with a positive or a negative velocity or happens to have a zero velocity, that is, happens to stand still, as in most of the examples mentioned above. We can speak of deflection in every case.

Now, if the wandering of an excitation through a neuron is comparable to the streaming of a fluid, we understand at once the possibility of the deflection of one nervous process by another. This deflection of a nervous process from its ordinary course is then no longer a strange phenomenon, but has become like an old acquaintance. We no longer ask any curious questions about it. We might, possibly, inquire after the physiological details of this function of the contact point or points of the two nervous paths, where the deflection is brought about. But our curiosity in this respect is not very great as long as we do not even know the kind of chemical changes which are conducted through the neuron.

We have spoken of a chain of neurons as if it were a tube through which air (or any fluid) is pressed from a reservoir containing air under higher pressure. There are, however, some disadvantages in picturing a nervous process in this way. There is actually nothing which resembles a reservoir from which any power or any substance enters, by way of a sensory point, into a chain of neurons in order to be pushed along; and this pushing by pressure might suggest a wrong idea of the function of the nervous system. Some one might think that, whatever it is that is pushed from a sensory to a motor point, it will take—like a rolling ball—only one way and entirely avoid all other possible ways. Thus, indeed, one finds nervous processes most commonly described in the older literature of neurology. The question would then have to be asked why such a process can take, now one, now another path, why it does not always take the same, since there is no god, no supernatural entity, in our nervous system to act as switchman, to sever the connections of the first path and to establish new paths, by voluntary action. This question is then unanswerable; the fact appears like a miracle. We must not think, therefore, of a nervous process as ever taking strictly a single path. We must, on the contrary, think of any nervous process as permeating the whole nervous system, but only along a certain path with great intensity, along all others with very small intensities. Only thus can we understand the function of the nervous system as a unitary function. It is, therefore, better not to think of the nervous process as something being pushed, but rather as a fluid filling the whole network of neurons and being attracted by, sucked in the direction of, all the motor points of the body. It is true, to those who are accustomed to imagine in mathematical terms movements of a liquid or a gas, there is no

essential difference between a stream of a fluid caused by pressure at one end and a stream caused by suction at the other.   But those not accustomed to mathematical reflections on such phenomena, will probably remember the all-permeating nature of any process in the nervous system more easily if they think of the cause of the streaming as something located in the totality of the motor points.

Let us, therefore, make the assumption, that the nervous system functions as if the neurons were tubes filled with a fluid, as if at all the motor points there were a constant suction tending to draw the fluid in the direction of each and every motor point, and as if an *excitation of any sensory point* were equivalent to a greater or smaller, but always minute, *opening of the tube* at this point, thus allowing a streaming motion of the fluid within the tube system.   When a system of tubes like the diagram of Figure 16, with *one-way valves* at all the meeting points of tube-units, is closed at all those points which we have called sensory points, no streaming of the fluid is possible in any of the tubes, in spite of the suction at all the motor points.   Another effect, however, results from the suction. The whole fluid in the tubes must assume a definite *tension*, whose force must become equal to that of the suction.   Then the tension remains constant until a stimulus is applied to a sensory point, or, as we have said, until one of the tubes is slightly opened at a sensory point. One must not think that immediately when the opening occurs, the whole column of fluid begins to stream.   What happens first, is a relief of the tension at the point where the opening is made.   Then, as in every elastic substance, so in the fluid, the relief of tension passes on.   Only when the relief of tension has reached the point where the force of suction is effective, that is, the motor point, can the

actual streaming begin. The velocity with which the relief of tension travels through the fluid, is exactly what is ordinarily called the velocity of sound in an elastic substance. In a neuron we have to call it the *velocity of the nervous process,*—whatever the nature of that process may be. The velocity of the nervous process, which may be regarded as a constant numerical value, and the length of the conductor leading from the sensory to the motor point determine, therefore, the time which elapses between sensory excitation and the start of the motor response.

The relief of tension, and the subsequent streaming, in a system like Figure 16, can take simultaneously many paths in the direction of a motor outlet. Which of all these paths is chiefly taken, is determined by the relative resistance of the conductors. We must not imagine,— as we have emphasized before and restate here in more detail—that the relief of tension rolls on like a ball, striking an obstacle, rebounding, running into an open channel, and so on, finally reaching one motor point exclusively. The relief of tension travels to every motor point which is directly or ever so indirectly connected with the sensory point in question. That it reaches motor points of direct connection sooner than those of indirect connection, is clear; but this time difference does not especially concern us at present. The streaming, subsequent to the relief of tension, also occurs everywhere,—in every neuron which is a chain in any path from the sensory point to any motor point. But the intensity of the streaming, the flux at any definite point within the nervous system, is necessarily determined by the relative resistance of the total path over this point (not the resistance of any single point) from the sensory to the motor point and the resistances of all the other paths leading from the same sensory point to all the motor points. To get a more definite

image of such a complicated phenomenon, let us think
of two incandescent electric lamps illuminating our room,
which in the ordinary manner are placed parallel into the
circuit. Suppose the wiring provides for two twenty
candle-power lamps, but we suddenly replace one of them
by a 200 candle-power lamp of correspondingly less
resistance. Immediately we see a diminution of the
brightness of the other lamp, because its higher resistance
keeps the current from passing through it in its normal
strength. Now imagine that in Figure 18, which is
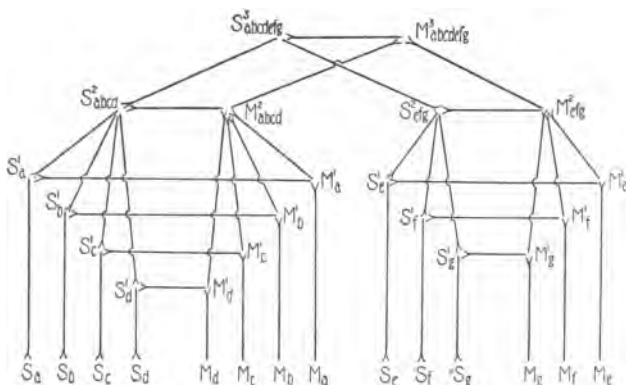
Fig. 18—Possible modification of details in nervous architecture.

merely a modification of Figure 16 on the same structural
principles, each neuron would be replaced by a thirty
volt lamp and that then the point S_a would be placed in
contact with the positive line, and all the M points in
contact with the negative line of a hundred and ten volt
electric circuit. It is clear that the three lamps of the
reflex arch $S_a M_a$ would then glow visibly, but that the
other lamps of the system would hardly glow at all,
although a weak current must pass through them. Simi-

larly, the muscular activity in the animal body becomes conspicuous only in the corresponding motor point, although a weak streaming must occur in the direction of every motor point in any way connected with the sensory point where the excitation starts.

If we thus picture the nervous process as a streaming of a fluid in a system of tubes, made possible by an opening at one of the sensory points, we must, of course, imagine this opening to be, even when at a maximum, very small relative to the volume of a tube unit. Otherwise the tube, or even the whole system, would quickly become empty, exhausted. The nervous system, however, is by no means quickly exhausted, but can be active for many hours before taking a complete, or nearly complete, rest during the period of sleep. The opening at a sensory point being exceedingly small, the streaming of the fluid must be very weak. This does not matter, since the flux in various neurons is significant only through its relative, not its absolute magnitude.

Two fundamental facts, with reference to the so-called instinctive activities of animal organisms, were to be explained: the deflection of one nervous process by another, and the simultaneous enhancement of the activity of several motor points. We have found that the former becomes comprehensible if we regard any nervous process as possessing the properties of a streaming fluid, provided the meeting points of the neurons, about whose functional properties we possess no actual knowledge whatsoever, are assumed to function in a manner comparable to the functioning of the simple mechanical device which is called a "jet pump." The simultaneous enhancement of the activity of several motor points can be satisfactorily explained as we have explained it in the preceding lecture, simply by an overflow and the inherited peculiarity of

nervous connections. If the excitation starting from S_a in Figure 17 is not in the ordinary way practically confined to the reflex arch $S_a\,M_a$, but exceeds the capacity of the reflex arch and overflows, it will reach on a higher level the connecting neuron $S_{a^3b^3c^3}\,M_{a^2b^3c^3}$ and hence pass down over the central point M_{bc}^2 to both the motor points M_b (and also M_b') and M_c. Since the overflow finds an outlet from the level of $S_{a^2b^3c^3}$ down, it does not reach the higher level of $S_{a^3b^4c^4d^4}$. This is important, for, if the overflow from S_a reached this level, the excitation starting from S_a would enhance the activity of the motor points M_d and M_d', instead of decreasing it by deflection, in accordance with our previous assumption concerning the significance of M_b, M_c, and M_d in the instinct under discussion. The deflection of the nervous process S_dM_d, however, can be insured by a sufficient difference in level between the connecting neurons which in Figure 17 are represented by $S_{a^3b^3c^3}\,M_{a^3b^3c^3}$ and by $S_{a^3b^4c^4d^4}\,M_{a^3b^4c^4d^4}$. This difference in level, of course, is not limited to what it appears to be in the simplified diagram of Figure 17. Only one question is thus left, namely, how we can speak of an *overflow* of a reflex arch $(S_a\,M_a)$ *upwards*, caused by the intensity of the excitation (at S_a), with the result that the activity of certain other motor points $(M_b$ and $M_c)$ is *not*, as would be expected from the principle of deflection, *weakened* by the strong nervous process (from S_a), but on the contrary *enhanced*. This is a question of so much importance that we cannot proceed without having answered it with perfect clearness. It is particularly important to make clear the difference between an overflow and the fact that in the case of every nervous process very weak currents always go over innumerable paths other than the main path of the process.

It is obviously not sufficient to state simply that the stronger nervous process deflects all weaker ones. There

are exceptions to this rule, as in the present case. Every case in which, because of a very great excitation at a sensory point, the motor response is not practically restricted to the corresponding motor point, but becomes positively apparent also at other motor points, is an exception to the principle of deflection. The stronger process, instead of canceling the motor effects at all motor points other than its own, while it may cancel many of them, enhances at least some of them, indeed may bring about some motor effects at points whose corresponding sensory points are not receiving any stimulation at all. Now, this can be understood only by assuming that there is an absolute limit to the flux in any neuron, or,—what amounts practically to the same and agrees better with our previous assumptions,—that the *resistance* of any neuron is not independent of the flux within it, but *increases* more and *more rapidly* as the flux increases. We are familiar with a similar phenomenon in electric conductivity. As the current increases, the conductor gets hot; and in the case of most substances its resistance becomes the greater, the greater the temperature. Let us imagine that there is a similar, only much more rapid, increase of the resistance with the increase of the flux in a conductor, and our problem is solved. If, under this condition, the excitation at S_a in Figure 17 reaches a sufficiently great height, the intensity of the flux in the motor neuron $M_a^1 M_a$ reaches practically an absolute maximum, and the *overflow*, which thus becomes inevitable, must seek the motor outlet which offers the least resistance because of the least length. This is in the present case the outlet over $S_{a^2b^3c^3} M_{a^3b^3c^3} M_{bc}^2$ into M_b, M_b', and M_c. Of course, there can be, then, no question of any deflection of an independent nervous process in $S_b M_b$ or $S_c M_c$. Whether there is any such nervous

process or not, the overflow from S_a into M_b and M_c would occur anyway. At the same time, however, the nervous process $S_d M_d$, if S_d happens to be simultaneously stimulated, is deflected into M_b and M_c, provided the overflow from S_a has not reached the level of $S_a{}^3{}_b{}^4{}_c{}^4{}_d{}^4 M_a{}^3{}_b{}^4{}_c{}^4{}_d{}^4$. Overflow and deflection, therefore, are not fundamental principles which logically exclude each other. Their conditions merely enter now and then into a conflict, a state of affairs which is found in all natural laws. Let us keep in mind, then, that we do not mean by overflow—as someone might conclude who has not read our present discussion carefully—the fact that any nervous process permeates, although for the most part exceedingly weakly, the whole nervous system, far beyond the limits of a narrow path:—we mean an overflow caused exclusively by an intensity of flux taxing the capacity of a nervous path to its limit.

We have called an instinct a selective and collective agency in the functioning of the nervous system. It is clear that the principle of deflection explains the selective, the principle of overflow the collective part of the function of an instinct, provided the inherited connections of sensory and motor points are such as represented diagrammatically in Figure 17.

SIXTH LECTURE

Tension of the total muscular system not interfering with special activities. The motor point not identical with the point that is moved. Fewer reflexes, more instincts in higher animals. The compounding of nervous elements into groups, of these groups into larger groups,. and so on, into a single nervous system. The nervous system of a worm. Nerve centers. Lower and higher centers. The nervous system of a crayfish. The brains of fish, frog, bird, and mammal. The nervous system of man. The cerebral hemispheres of man.

SINCE we have had occasion to mention again at the end of the last lecture the fact that every nervous process permeates, although for the most part very faintly, the whole nervous system and thus, in a manner, reaches every motor point, we may explain briefly, that this does not conflict with our observations of actual animal behavior. A slight degree of tension of all our muscles in no way interferes with specific activities involving a few definite muscles. Indeed in practically all our normal activities we find that at least one group of muscles other than those which actually pull is quite noticeably under tension, namely the so-called antagonistic muscles. Raise your arm in order to take off your hat. It can be easily observed, and there is no doubt whatsoever, that during the upward movement of the arm not only those muscles are under tension which pull the arm towards the head, but also those which under

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other conditions might pull the arm towards the body. The latter muscles, if we put our fingers on them, do not feel relaxed, flabby, but somewhat stiff. Only, the former muscles feel stiffer, they are under greater tension, and the arm, therefore, follows the direction determined by them. Under these circumstances, a general but faint permeation of the whole nervous system by any nervous process, however definite the activity for whose sake this process exists, involves by no means a contradiction.

Speaking of muscles, it may be well to make a remark here which will help to avoid possible misunderstandings later. When a nervous excitation causes a movement of a definite part of the body, for example, of the arm, the motor point of the nervous path is not necessarily located in that part of the body, in the arm. Indeed, if a movement of the arm as a whole is in question, the motor point (more correctly, of course, points) must be in the muscles located at the shoulder and the front or back of the chest. The muscles located in the arm can not move the whole arm, but only the lower arm. The muscles located in the lower arm can not move the lower arm, but only the hand and the fingers. These examples may suffice to call attention to the fact, which is self-evident, that in highly developed animals the motor point must not generally be looked for in that part of the body of whose activity the nervous process is said to be the signal.

We have thus far spoken of the fundamental facts of behavior in higher animals under two headings, that of reflex and that of instinct. We call an animal the *higher*, the fewer simple reflexes it has—relatively—and the more instincts. Since this difference in the relative number of simple and compound reflexes, that is, of reflexes proper and instincts, depends, according to our previous exposi-tions, on definite structural peculiarities of the nervous

system, it seems interesting and promising to compare lower and higher animals with regard to the structure of their nervous systems. It is not a priori necessary, but probable, that these structural differences become apparent to the eye of the anatomist and zoologist, and if they do, they permit the correctness of our previous expositions to be tested.

As our lowest type may serve the nervous system of an earth worm. Figure 19 shows the arrangement of the more bulky masses of the nervous system, omitting the many fibers which are found scattered over the body and which obviously serve as sensory and motor neurons.
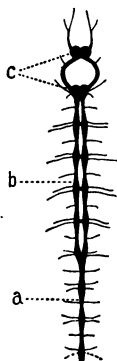
Fig. 19—The bulk of the nervous system of an earth worm.

What we see in the figure represents, therefore, in the main, merely the bulk of those connecting neurons which are added to the sensory and motor neurons in order to complete the reflex arches, and of those which serve to establish connections among the reflex arches, in accordance with the principles which we have discussed. We have seen that the frequent necessity of a body *acting as a whole*, the necessity of *local responsiveness* as found in the reflexes, and the presence of selecting and collecting agents

called *instincts*, have as a consequence a structure of the
nervous system like the diagrams of Figures 16, 17, and
18.   Let us, at present, remember especially Figure 18.
We notice there a number of sensory and motor points.
Some of the reflex arches are united by the connecting
neuron S^2_{abcd} M^2_{abcd}.   The significance of the formation
of such a group is obviously, together with the insurance
of local responsiveness for each reflex arch, a unification
of the group of reflex arches for the purpose of co-opera-
tion.   It is clear that co-operating reflex arches, as a rule,
belong to, and so far as possible are located in, the same
part of the body.   Any part of the body which deserves
to be called a limb or an organ, say, one finger, needs
unitary activity of the totality of its own reflex arches for
the sake of its own protection if not for other ends.   This
part of the body, then, is as a whole subject to the principle
of local responsiveness, but must also be able to co-operate
with other organs, to form with them anatomically and
functionally a larger organ.   For example, our fingers
are united in our hand, not only anatomically, but also
functionally, that is, by their nervous connections, thus
making the hand a larger organ.   We know that it is
easier to make a fist than to bend each finger separately.
These considerations lead us to expect groups of reflex
arches to be united as we see two such groups united in
Figure 18, where the central sensory points S^2_{abcd} and
S^2_{efg} and the central motor points M^2_{abcd} and M^2_{efg} are
connected as if they were peripheral sensory and motor
points.   The larger organ which is only thus made "an
organ," enabled to function as a unit in addition to
possessing local responsiveness of its sub-divisions, must
again, perhaps, be united with other organs.   That is,
the whole mass of nervous conductors, sensory or motor,
must again be united with similar masses—we might just

as well say, systems—into a larger "nervous system."
Where this building reaches its final culmination, depends
exclusively on the anatomical development, the anatomical
complication, and, accordingly, the demands of the body
for nervous conductors to suit its functional needs.   A
simple way of representing this compounding of sensory
and motor elements into groups, of these groups into
larger groups, of these into still larger groups, and so on,
finally into a single large system, is shown in Figure 20.
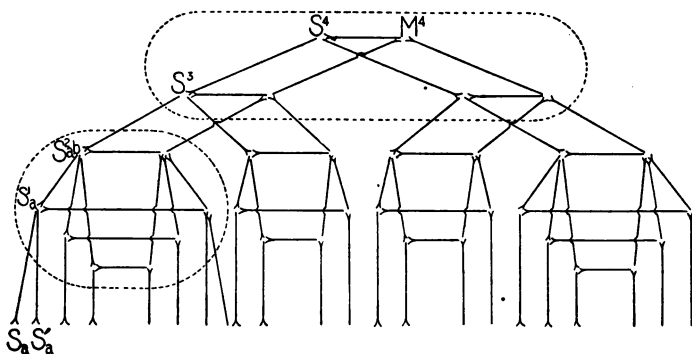
Fig. 20—Low and high centers: group formation in the nervous system.

That the total mass of all nervous conductors thus forms
a single system, and not two or three or more mutually
independent systems, follows from the necessity of each
animal body being able to act as a whole.   In the figure,
each group is composed of only two members, for sim-
plicity's sake.   In the body each group must actually
contain, of course, a very large number of elements, in
accordance with the special anatomical and functional
demands.   This large and varying number is represented
in the diagram almost throughout by two.   The dotted
lines of the figure will be explained a little later.

Let us now make the application to the earth worm. Let us see what kind of a picture we can expect the earth worm's nervous system to present to our eyes. Since the worm's body is long and narrow, we expect that successive pieces, from the front to the rear, should function in relative independence. To make this still clearer, let us remember how the worm moves forward. The abdominal side of the body possesses tiny bristles pointing backwards, so that the body does not easily slide backwards on the ground. If, then, a fraction of the body, at the front end, lengthens in the manner which everybody knows from observation, the front end must be pushed forward. Suppose now the first half of this front end, the head, so to speak, remains inactive on the ground, but the second half actively shortens, and an equally long piece directly behind actively lengthens. The effect must be that the elements of the piece directly behind the head are, more or less, pushed forward. If now the piece which has just lengthened, contracts lengthwise, and the directly following piece lengthens at the same time, while all the rest of the body remains inactive on the ground, the elements of the third piece are pushed forward, more or less. When in the same way every successive piece has been moved forward, we can say that the worm as a whole has made a step forward. It is immediately clear that the nervous system of this animal must be so constructed that the successive pieces can function in relative independence. They must be nervously furnished in such a manner that they can function like so many separate organs, that they possess as wholes what we have called local responsiveness. This means that the reflex arches of each piece must be united into a group, schematically like the groups of reflex arches in Figures 18 and 20. We learn from the figures that this

unification of the reflex arches adds a considerable number of nervous conductors to those making up each group of reflex arches,—conductors which must be found rather close together, for the sake of the unifying function in question. We must expect, then, to find along the worm, here and there, something like clumps or nodes of nervous substance. Look at Figure 19, where these nodes are apparent. The nervous cord which runs lengthwise through the body shows a number of points where something is added. Where the cord is a plain cord, the addition is simply a swelling, a node, for example, at *a*. Where the cord is a double cord, in the front part of the body, for example, at *b*, the addition appears as a kind of tie between the parallel divisions, giving the whole a ladder-like form. These morphological details, of course, do not concern us much at present. The important fact is that we actually find the addition, at fairly regular intervals, of nervous substance to the cord, which confirms our view that the whole nervous cord must be organized in successive groups of reflex arches.

The most conspicuous of these clumps of nervous tissue are the two belonging to the head of the worm, at *c*. It may be well to mention that the two parallel divisions of the nervous cord are here, between these two nodes, more widely separated, in the shape of an oval, because the alimentary canal, from the mouth, passes through between the two divisions of the nervous cord. If we can speak, in the case of the earth worm, of instincts, that is, if there are nervous functions sufficiently complicated in their sensory and motor aspect and also sufficiently unitary to be called instincts, they must be related to the head rather than to any other part of the body. The head is, even in the earth worm, the most complicated and most important .motor organ. Food is taken in by the head.

The direction of locomotion is determined largely by the direction taken by the head. The head, therefore, must contain many important groups of muscles; but also many important sensory points, for the taking in of food and the direction of locomotion are determined by the nervous stimulations coming from the external objects surrounding the head. It is quite natural that all these important sensory and motor points must be connected by a highly complicated—and therefore somewhat bulky—system of nervous conductors, forming out of the many reflex arches as many different functional groups with manifold interrelations as the life activities of the animal require. This, then, is the cause of the accumulation of nervous tissue in the head, which far surpasses the accumulation of nervous tissue at any of the other nodes of the cord just mentioned. That there are *two* such accumulations in the head is, from our point of view, a mere accident. It is, of course, the consequence of the anatomical distribution of the head organs. If the anatomy of the head were different, both masses of nervous tissue might appear united into a single node correspondingly larger. And if the anatomy of the head were still different, there might be three, four, or more nodes, each correspondingly smaller.

A name for these nodes has long been adopted, which we must use here too in order to adjust ourselves to the common usage of language. They are called *nerve centers.* We need not discuss the value of this particular name,—it has become so common that we cannot escape using it. However, it is well to keep any literal meaning of the term entirely out of mind. A "center" has no more literal meaning for us in the nervous system than a "central" has in a telephone system. We know what it is convenient to mean by it, in the one case as in the other. It is cus-

tomary to speak, not only of nervous centers in general, but of *higher and lower nerve centers*. The significance of this distinction can now be easily understood. If a "nerve center" is a system of neurons serving the purpose of uniting reflex arches into groups and such groups again into more comprehensive groups, it must be called the higher, the farther removed it is from the sensory and motor points of the body. Still, the word center can be used in a broader or in a narrower sense. In Figure 20, we may call all the neurons enclosed within one of the dotted lines a center. Which of them is higher, more removed from the peripheral sensory and motor points, is immediately clear to the eye. Or, we may take the term center in a narrower sense and include only the connecting neuron between a central sensory point (for example, S_{ab}^2) and its corresponding central motor point (M_{ab}^2), and the adjoining parts of those neurons which from this central sensory and this central motor point run in the peripheral direction. In this sense the neuron $S_{ab}^2 M_{ab}^2$ plus the adjoining parts of the four neurons $S_a^1 S_{ab}^2$, $S_b^1 S_{ab}^2$, $M_{ab}^2 M_a^1$, $M_{ab}^2 M_b^1$ would be a nerve center as represented in this diagram. (The reader is requested to supply the lettering of Figure 20 according to the rules given on page 49.) In this narrower sense likewise the distinction between higher and lower nerve centers is immediately clear to the eye. The nerve center of which we just spoke, containing the points S_{ab}^2 and M_{ab}^2, is much lower than the nerve center containing the points S^4 and M^4. It seems that we may use the term nerve center in either sense without fear that any consequences arise which might make our future discussions ambiguous.

We need not prove that the so-called higher animals possess higher nerve centers than the lower animals, for the greater complication of their nervous system and the

resulting greater complexity of their life activities is the very reason why certain animals are called higher in comparison with others which then, of course, are called lower animals. But just on account of this fundamental significance of the terms lower and higher animals, it is exceedingly interesting to study the appearance of the bulk of the nervous system in a series of higher animals as we have studied it in a rather low animal, the earth worm. Let
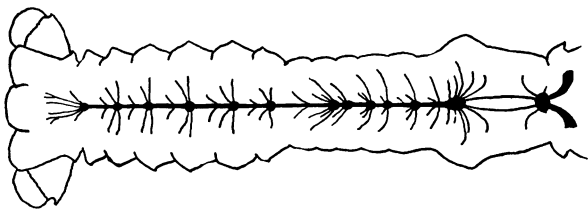
Fig. 21—Nervous system of a crayfish.

us now use as an example a crayfish (Figure 21), which has a somewhat higher position in the animal scale than a worm. There is no essential difference between the nervous system of the crayfish and that of the earthworm. We notice, however, that the bulky parts of the nervous system, the nerve centers, are relatively bigger. This is to be expected, since the crayfish has numerous appendages, specialized organs which must co-operate for various ends and could not co-operate if their systems of reflex arches were not combined by connecting neurons into a sufficient number of systems of a higher order.

The vertebrates have their more important sensory and motor organs still more concentrated in the head than the articulate and lower animals. The reflex arches of each of these organs must be united into a group, and these groups, again, must enter into manifold combinations in order to serve the more varied needs of a more complex organism. Accordingly we find in the head of a

fish that particularly large accumulation of nerve centers which we call the *brain* (Figure 22). That this group formation of reflex arches, this development of higher and higher centers is most conspicuous in the head, is the direct result of the greater importance of the sensory and motor organs of the head than of the other parts of the body. The important reflex arches of the head must be well co-ordinated among themselves, but the systems of nervous conductors thus formed must also be well co-ordinated with the less important reflex arches in other parts of the body. However, among the latter reflex arches
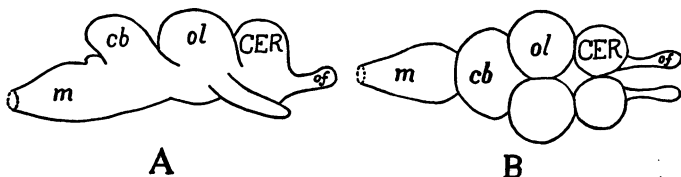
Fig. 22—Brain of a fish; double view.

there are a certain class which do not require a particularly close connection with the reflex arches of the head. They are the reflex arches which serve the so-called vegetative or visceral functions of the body. Let us make this clear by examples. The approach to a particular article of food is controlled mainly by the reflex arches of the head: it is a response to sights, sounds, odors received by the sense organs of the head. But the approach could not take place without the co-operation of the reflex arches on which the locomotor organs depend for their function; and these organs are to be found in the remainder of the body rather than in the head. On the other hand, there is scarcely any reason why the intestinal activity of digesting the food should be enhanced or impaired or otherwise influenced during this or any other specially directed

locomotion of the body, or why this special locomotion should be influenced by the intestinal activity, save the extreme cases of an empty or an already overloaded stomach, to use familiar language. We are not surprised, then, to find in any animal the visceral or interoceptive nervous system rather separated from the locomotor or exteroceptive nervous system, and to find in the nervous accumulation of the head which we call the brain "the center" not so much of the whole nervous system as of the latter part only, of the exteroceptive system.

In comparing different vertebrates, let us consider of the whole nervous system this part accumulated in the head, the brain, alone and compare the relative size of its main subdivisions. For this purpose we give to the sub-divisions their ordinary names. We notice, in Figure 22, that there are five sub-divisions, of which three, the frontal ones, are more obviously divided into a right and a left part than the other two. To these accumulations of nervous tissue the term ganglion might be applied, as also to any of the bulkier parts of the nervous systems of the crayfish and the earth worm in Figures 21 and 19. Or they may be called lobes, a term frequently applied to sub-divisions of the brain. Thus, in Figure 22, *ol* means "optical lobe," *of* "olfactory lobe." In the same figure *m* stands for the "medulla," joining the cord, also called bulb because of its shape, *cb* for "cerebellum" or small brain, *CER* for "cerebrum" or large brain.
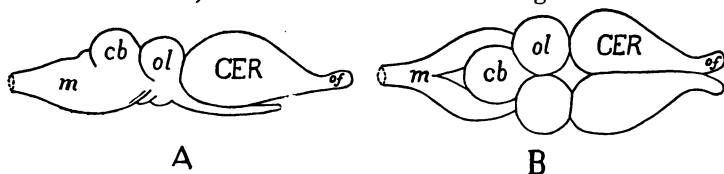
Fig. 23—Brain of a frog; double view.

Compare with these ganglions of the fish the same ganglions of the frog, as shown in Figure 23. Their relative size has changed in favor of one, the cerebrum. This is still more obvious in a still higher animal, a bird.
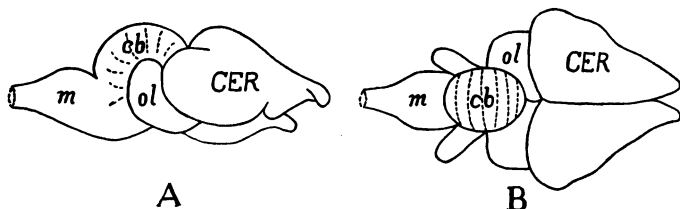
Fig. 24—Brain of a bird; double view.

The two halves of the cerebrum, the so-called hemispheres, are now, especially in the view of Figure 24, B, the most conspicuous part of the whole. The same development continues when we pass, in Figure 25, to a mammal. The hemispheres of the cerebrum begin to look as if they were the whole brain. The optical lobes have indeed
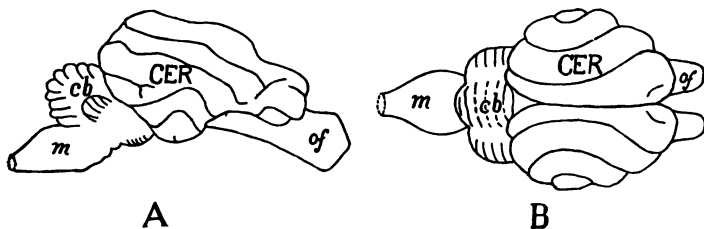
Fig. 25—Brain of a lower mammal; double view.

been so completely overlapped by the ever growing hemispheres that they have disappeared from sight. This continued growth of the same single ganglion—quite aside from a continuous, but less marked growth of all others—through the various stages of evolution of the vertebrates illustrates a principle different from that

which requires a bulkier nervous system for an animal possessing a greater number of sensory and motor points. This continued growth of a single ganglion can have a meaning only if the ganglion thus growing does not serve any peripheral points directly, but exclusively indirectly, by interconnecting unified neuron groups and unifying them into secondary and further derived groups, as shown diagrammatically in Figure 20. The growth of this ganglion, then, enables the animal more and more to
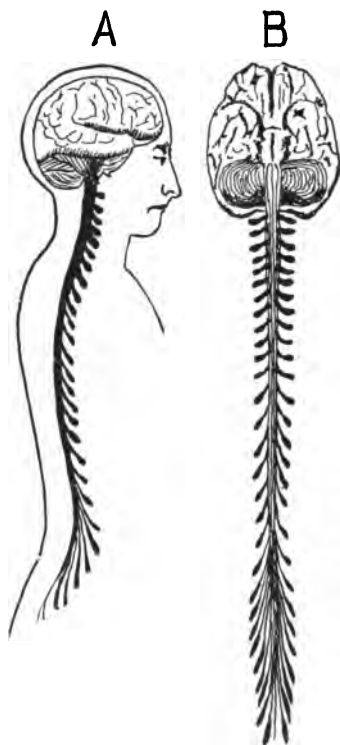
Fig. 26—Nervous system of man; double view.

react at any motor point to an excitation occurring at any sensory point whatsoever, without losing its indispensable local responsiveness.

If we compare (Figure 26) the bulky part of the nervous system of man, that is, the part which can be cut out of the body with comparative ease, and the bulky part of the nervous system of a worm (Figure 19), we see that they are not unlike in appearance except for the fact that to a nervous system like that of the worm man has added the enormous mass of nervous tissue of the cerebral hemispheres (and, we might add, to a lesser extent the cerebellum) serving no other purpose than that explained in the last paragraph. Along the two sides of the spinal cord, in Figure 26, there are two rows of ganglions somewhat separated from the cord. They obviously group the reflex arches of each side and thus make the organs on one side of the body relatively independent of each other and of those of the other side. Many of our activities, it is true, are of the symmetrical kind, requiring co-operation of the motor organs symmetrically situated. But not a few of our activities are one-sided. The reflex arches of a certain region of either side are therefore united in a ganglion before coming into connection with the nervous conductors of the spinal cord.

Figure 27 shows the enormous development of the cerebral hemispheres in man as compared with those of the lower vertebrates represented in Figures 22, 23, 24 and 25. The cerebrum has grown to such an extent that it hides practically all the other parts of the brain, so conspicuous in the fish, the frog, and the bird. The cerebral hemispheres, which in the mammals have fallen sideways over the other original ganglions of the brain, have further grown especially in the forward direction, thus covering their own lateral parts and forming the

large Sylvian fissure (at *S* in Figure 27).   Only toward the back a piece of the cerebellum is still left uncovered. The cerebrum has become practically the whole brain. Its growth, taking place in the brain exactly there where the most pronounced growth took place during the immediately preceding period of evolution, has every time served to make possible interconnection of the highest centers by still higher centers, thus bringing about an ever increasing possibility of any imaginable group of the seemingly most unrelated motor points being functionally
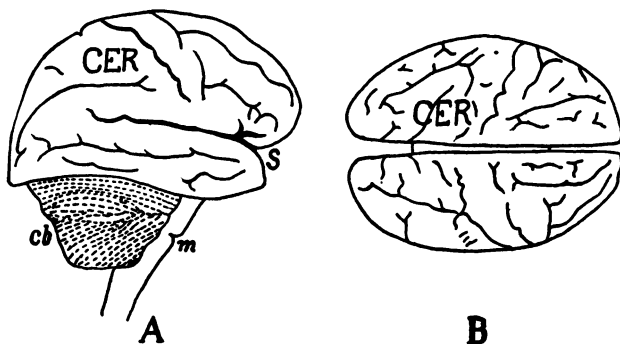
Fig. 27—Brain of man; double view.

governed by any group of seemingly most unrelated sensory points.   We need not suppose, however, that in this process of complication identical with unification, evolution has reached its highest possible mark.   We should over-estimate our race if we thought so.   There are many indications—some of them we shall have to mention later—that the functions of innumerable reflex arches and groups of reflex arches are even in the human race still practically independent of, never governed by, the function of those, belonging to the majority, which are already effectively unified by their connections with the brain and especially with the cerebral hemispheres.

SEVENTH LECTURE

Learning. The susceptibility of nervous conductors. Variations of the nervous path. (1) Two kinds of variation of response. (2) Sensory condensation. (3) Motor condensation. Graceful motion. Inhibition. How a child comes to fear a fire.

THUS far we have spoken of animal activities only under two heads, as reflexes, and as selected groups of reflexes, that is, instincts. Both these kinds of activities may be given a common name. We may call them hereditary activities, because the characteristic response following each particular stimulation is in these cases completely determined by the strictly biological inheritance of the individual from his ancestors,— is in no way shaped by the geographical and social inheritance resulting from the fact that the individual has been given by his ancestors life and the training of his youth in a particular geologic-physical and social environment. This shaping during life of the individual's manner of acting may be referred to by the word "learning," or by the word "habit." We are, perhaps, inclined to use the word "learning" chiefly in connection with social institutions, "schools" of all kinds, "habit" chiefly in connection with altogether fortuitous circumstances. For us, however, in this treatise, these words are synonymous. Regarded as phases in the behavior of the human or animal individual,

acquiring a habit and learning are identical. In each animal we find — the higher the species to which the individual belongs, the more numerous—learned or habitual, in addition to hereditary, activities. Our next task is the description of the changes which hereditary nervous activities undergo in order to become habit,—the description of the process of learning, or rather, of the various kinds of processes of learning.

It is plain that any shaping during life of an individual's sensori-motor activity presupposes: first, that there is a *variation* in the succession of sensory excitation and motor response, and secondly, that this variation is *fixed* and thus caused to reappear. The variation is possible only if the main flux of the excitation once takes a path different from the one which is to be expected according to the shortest hereditary connection of sensory and motor points. The fixation of this path is possible only if (we might also say: fixation means that) nervous conductors are in some way *susceptible* to excitations traveling through them, so that one of the reasons why an excitation may be thought to choose a particular path, is simply this, that it has once before taken this path. Of course this statement may, and must, be made more definite with respect to our assumption that the main path of the nervous flux is the path of least resistance. We must say, then, that the *susceptibility* of nervous conductors consists in their resistance being reduced by a flux occurring in them,—this resistance to stay reduced for a considerable time after the flux has terminated. We may add, at once, remembering that the counterpart of learning is forgetting and that forgetting is a gradual process: that we have the right to assume that the reduced resistance of any nervous conductor slowly rises again to its original measure.

The question then is: do the pictures of streaming which we have used in order to have before our mind a clear idea of nervous activity and its peculiarities, aid us also in imagining the susceptibility of a neuron as one of its natural properties? It seems that this question can be answered unhesitatingly in the affirmative. We are hardly more familiar with any other natural event than that of a stream broadening, washing out its channel; and a dry river bed being gradually obliterated by being filled with debris and dust is not a very unusual phenomenon either. Our picture of nervous activity, with regard to the susceptibility of conductors, is therefore quite consistent. The question is then left, if it is also consistent with regard to the possibility of a variation of the main path along which the excitation is conducted. Now, this question has been answered already, in our discussion of instinct. We said that an instinct is not only a collecting, but also a selecting agency, and we explained the selection of a path for an excitation, by referring to the familiar physical principle underlying the action of a jet-pump. No further assumption is necessary, only a reference to an assumption already made. A variation of the main path taken by an excitation can, accordingly, be the result of a second nervous process deflecting the first by dint of its own greater intensity. That a variation of the nervous path can be brought about also by other factors, without any deflection, will appear later.

We may distinguish several classes of *variation of the nervous path*. If the stimulation as well as the motor response is so simple that the whole nervous activity can be called a reflex, the variation of the nervous path can consist either in the motor response occurring at a motor point which is not the point corresponding to the sensory point stimulated or in the very same motor response following

the application of a stimulation to a point which is not
the corresponding sensory point. Let us use *variation
of response* as a technical term for this kind of variation
of the nervous path. Naturally, we can apply the same
term also to cases in which the nervous path is neither at
its sensory nor at its motor end quite so simple. Indeed,
looking for a striking concrete example, we can hardly
help giving one in which the nervous path is complex. A
small child, taking beer into his mouth, spits it out,
reflexly,—or rather instinctively, for the motor activity
may be quite complex. Any bitter substance stimulates
definite sensory organs of the mouth, and the motor res-
ponse of the facial and other muscles is that which we call
spitting. The bitter substance is thus removed. The
large number of people who habitually drink beer can have
acquired this habit only by a variation of response taking
place and becoming fixed. Once, instead of spitting,
the very different motor response of swallowing occurred,
as a variation, and this variation, becoming fixed, became
the habit of drinking beer. In this example a different
response came to follow the same stimulation. As an
example of the same response following a different stimu-
lation we may mention this. A baby, during the first
three or six weeks of his life, responds to any sudden noise
by quickly closing his eyes. It is easy to observe this.
One need only clap his hands or whistle in order to see the
baby wink. On the other hand, one may closely approach
the baby's open eye with a finger or a stick without caus-
ing the slightest winking, unless the eye is actually touched.
When the baby is a few months old, all this has changed.
Noises rarely call forth the response of winking, but
when any object is brought near the eye, the latter is
closed. This reaction then remains our habit all through
our adult life. Once, of course, the variation must have

occurred for the first time,—the variation of the nervous path which consists in a visual stimulation taking the place of an auditory stimulation, while the motor response remains the same.

If the stimulation is complex and the motor response correspondingly complex, the variation of the nervous path can consist in the complex response being called out by a greatly simplified stimulation, possibly a stimulation of a single sensory point. The habitual nervous activity then becomes similar to an instinct, for a complex reaction in response to a simple stimulation is, as we have seen, characteristic of an instinct. In order to have a brief term for this kind of a variation of the nervous path, let us call it *sensory condensation*, thus referring to the fact that at the sensory end of the system of nervous conductors the flux (when represented reversely in a diagram) no longer spreads out, but is condensed into a narrow channel.

An example, rather complex in all its aspects, but very familiar and therefore well illustrating our case, is the following. In playing a certain piece of music on the piano, at a particular place in the music each one of several fingers has to perform a definite movement,—what movement, is indicated by as many notes as there are fingers to move. The beginner, in order to strike the correct chord, looks at every note. But after some time of practice, we observe that he plays exactly the same complicated chord even when some of the notes, without his knowledge, have been erased or changed by us. Obviously these notes are no longer needed for the response, and a simpler stimulation now brings about the same motor response. Typewriting, reading, proofreading, weaving, attending to any machine, —any kind of skillful activity can illustrate this same kind of variation of the nervous path. The complex activity is ultimately called forth by a part of the original stimu-

lation; sometimes to the detriment of the subject, as when a proofreader overlooks a typographical error, reading the whole word although not all of the word is there to act on his eyes.

If the motor response is complex (because it is an instinctive response or the stimulation is complex), the variation of the nervous path can consist in the response being greatly simplified, possibly reduced to a response at a single motor point. Thus it would become similar to a reflex response, were it not, perhaps, for the complexity of the stimulation. In order to have a brief term for this kind of variation of the nervous path, let us call it *motor condensation*, thus referring to the fact that at the motor end of the system of nervous conductors the flux no longer spreads out, but is condensed into a narrow channel. Watch a child receiving his first instruction in writing and you will frequently observe, not merely a moderate activity in the shoulder, wrist, and finger joints, as when an adult is writing, but in addition to an excessive activity in these joints a tense bending of those fingers of the writing hand which do not hold the pen, and also of the fingers of the other hand, even a twisting of the head and the feet as if no writing were possible without them. We say in such a case that the person acts awkwardly. The disappearance of awkwardness is generally equivalent to the dropping of all movements unnecessary for the end in question. A graceful motion is simply a motion no element of which appears to be superfluous. The acquisition of graceful motion means motor condensation. • Of course, our distinction of three classes of variation of the nervous path, variation of response, sensory condensation, and motor condensation, does not imply that each of these variations must occur in separation from the others. On the contrary, we must expect to find

in actual life usually mixtures of them. As example of such a mixture may serve the behavior of a person falling into a river. If this is his first experience of the kind, the motor response is exceedingly complex. The hands move about in all directions, but chiefly they are thrown up in wild attempts to catch anything which might be in reach—a straw, as the proverb says—while the feet make movements which, when slowly executed, might be useful in climbing a tree, but which can serve no very useful purpose in the surrounding fluid. The skillful swimmer, on the other hand, merely makes a few moderate downward strokes with his outstretched arms and hands, and thus reaches the surface and stays there, possibly not moving his feet at all. The variation of the nervous path in this case obviously consists in a variation of response as well as a motor condensation. As a matter of fact, a sensory condensation is also involved, for during the process of learning to swim many stimulations of various sensory points (perhaps a teacher's words and example) are effective, which later become superfluous.

The process of learning, the acquisition of a habit, has a negative aspect of great importance, so far as the motor end of the nervous activity is concerned. What a person does *not* do, whether he reacts towards his physical or social environment in a definite way or remains inactive in this way, is frequently of the greatest consequence to others. When I am walking along a highway and meet strangers, my chief interest is in not being attacked and robbed. What they positively do, concerns me but little, possibly not at all. How important the negative aspect of human activity is appears from the fact that the great moral law of the decalogue contains almost exclusively negative rules. Our scientific interest, therefore, can not be restricted to the positive aspect of an individual's

motor actiyity,　It is clear, even from the mere outline of nervous activity as given thus far, that the negative aspect of the motor result of a nervous process can never be a reduction of a nervous excitation to *nothing*, but only a *deviation* to a motor point other than the one at which we had a certain right, according to our knowledge of the nervous connections, to expect its motor response.　When we are interested in a person's or animal's *not doing* a certain thing, we use as a technical term the word "inhibition."　From the point of view of this treatise, *inhibition* means that the individual *does something else* instead of what we thought or feared he might do, *while we do not care what it is that he actually does*.　From a purely neurological point of view the term inhibition in this sense is superfluous. Nevertheless we shall have to use it because of its great significance from the social point of view, for many social institutions of great importance, for example all those connected with crime and criminal law, cannot do without this concept of inhibition.　The law which inhibits murder by stating "Thou shalt not kill" does not state what we shall do instead of killing.　The law giver is not concerned with our action provided it does not consist in killing. But it is of great value to us in any sociological application to be aware of the fact that, at the bottom, the prevention of crime is not a problem of preventing action, but altogether a problem of *substituting* a socially valuable reaction to a certain stimulation for a socially harmful reaction.

Thus far, we have hardly done more than define the terms, variation of response, with its negative aspect inhibition, sensory condensation, and motor condensation. We must now make clear in detail, in specific instances illustrating these cases, what goes on in the nervous system when the nervous path is modified and this modifica-

tion becomes fixed,—to make sure that the fundamental
assumptions hitherto put down are sufficient for an under-
standing of the behavior of any animal, even the highest,
or that they must be supplemented in a particular way.
Let us study in detail, first, the fundamental nervous
processes underlying the "education" of the proverbial
child who learns to fear the fire. This is a variation of
response. The instinctive activity called out by the flame
impressing the sensory points of the eyes consists in
a drawing nearer of the body or its limbs to the flame.
The habit which exists in later life is a withdrawing of
the body or its limbs from the flame. The variation
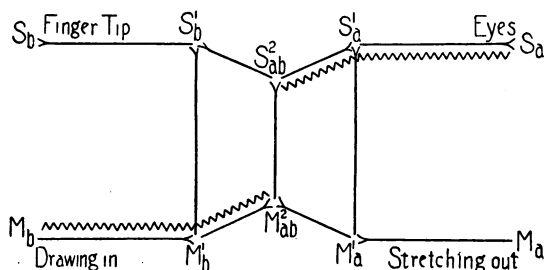
Fig. 28—Burnt child fears the fire.

of the nervous path, therefore, must consist in this, that
the excitation coming from the eyes, which at first
passes into certain muscles, for example, those stretch-
ing out the arm, later passes into the very antagonis-
tic set of muscles, drawing in the arm. In Figure 28 we
represent this schematically as if the eyes stimulated
were only a single sensory point (S_a) and each of the
muscle sets only a single motor point $(M_a$ approaching,
M_b receding). The only difference from our previous
method of drawing the figures is that the two reflex arches
open in opposite directions, right and left, instead of both

downwards. S_a and M_a are corresponding points. It is natural, therefore, that the child's finger is stretched out toward the light. The problem is how we can explain that later the path $S_a S_a^1 S_{ab}^2 M_{ab}^2 M_b^1 M_b$, marked in the figure by a zigzag line, has a lesser resistance than the path $S_a S_a^1 M_a^1 M_a$, so that then the finger is withdrawn as soon as the flame becomes simply visible. We have stated that such a change must mean the fixation of a variation, and this variation may be the result of a second nervous process deflecting the first one from its original course, in the direction of M_a, to another course in the direction of M_b. The second nervous process, therefore, must have M_b as its motor end. What kind of a sense organ is then represented by the sensory point S_b, corresponding to this motor point M_b? We know that the drawing of limbs toward the body, while resulting from many different stimulations, is especially the result of pain stimulation. An animal suffering from strong pain of any kind does not stretch out its limbs, but draws them in, curves them, and the whole body too, if possible. It writhes. We know further, from direct and indirect experience, that pain stimulation is quite generally the essential factor in any kind of variation of response. S_b represents, therefore, the pain nerve ends of the finger stretched out. In what way, then, in our diagram of Figure 28, do the two nervous processes, from the eyes and from the finger tip, influence each other?

In order that one of two nervous processes deflect the other from its course, they must obviously exist in the nervous system (Figure 28) simultaneously. This does not imply, however, that one of them may not begin before the other. In our case, S_a is stimulated first, and only because of the excitation traveling from S_a to M_a and causing the finger to approach the flame, occurs

stimulation of S_b by the flame. From this moment on S_a and S_b are stimulated simultaneously. Whether now the finger is moved into the flame or away from it, depends, so far as it is a strictly mechanical event, simply on the relative force with which the one (at M_a) or the other (at M_b) of the antagonistic sets of muscles contracts. This muscular force here depends on the relative intensity of the nervous flux towards M_a and towards M_b. It seems rather obvious that the excitation at S_b, caused by the burning of the finger in or near the flame, must be exceedingly strong, so that, as a purely mechanical effect, the reaction must be that of a withdrawal. But even if the two reactions were not as mechanical phenomena mutually exclusive,—even if they were not antagonistic, but anatomically independent movements,—*the laws of nervous function alone* would practically suppress the one in favor of the other, because the stronger nervous process would sufficiently deflect the flux of the weaker nervous process. It is this suppression of one nervous process by another nervous process (and not at all the mechanical annihilation of one muscular pull by another) which we are here concerned with. Let us see how this is brought about.

The flux originating from S_a divides at the point S_a^1. The larger part of it takes the path $S_a^1 M_a^1$; a smaller part the path $S_a^1 S_{ab}^2 M_{ab}^2 M_a^1$, because the resistance of the latter is, according to the diagram, three times that of the former. It is evident that at the point M_{ab}^2, too, a division of the flux must take place. Although the resistance of the path $M_{ab}^2 M_b^1 M_b$ is no greater than that of the path $M_{ab}^2 M_a^1 M_a$, most of the flux must go on from M_{ab}^2 in the direction of M_a^1, because the flux over $S_a^1 M_a^1 M_a$, according to our assumptions, acts as suction upon the contents of the conductor $M_{ab}^2 M_a^1$, whereas

no similar force acts in the direction of M_b^1. Practically all of the flux which originates from S_a finds its outlet therefore in M_a, only an insignificant fraction going to M_b. But immediately the excitation of the point M_a brings about the strong stimulation of S_b, the outstretched finger being burnt. A strong flux now goes on from S_b to M_b, mostly over $S_b^1 M_b^1$, partly over $S_b^1 S_{ab}^2 M_{ab}^2 M_b^1$; but even the part taking the latter path is strong compared with the flux originating from S_a.   At once all the conditions are changed which determine the flux originating from S_a. The strong current over $S_b^1 S_{ab}^2 M_{ab}^2$ draws the contents of the conductors $S_a^1 S_{ab}^2$ and $S_a S_b^1$. Consequently most of the flux from S_a^1 takes the direction of S_{ab}^2; little takes the direction of M_a^1. From M_{ab}^2, again, most of the flux is drawn, by the strong current over $S_b^1 M_b^1 M_b$, in the direction of M_b^1; little in the direction of M_a^1, since the weak current over $S_a^1 M_a^1 M_a$ draws only weakly in this direction. All this will appear even more natural to us when we recall that in our physical analogy, the jet-pump, the suction effect is not simply proportional to the velocity of the fluid, but to the square of the velocity. We have the right to assume, therefore, that the flux of a weak nervous process is very readily consumed by the deflecting effect of one which is only considerably stronger. Consequently, in spite of the continuance of the stimulation at S_a (the eyes), there is now practically no motor excitation at M_a (no tendency to stretch out).

How is the fixation of this variation brought about, to the effect that later, when S_a is stimulated, the response occurs at M_b, without any stimulation at all occurring at S_b? We have assumed that each neuron is susceptible to any flux occurring within it, so that its resistance is lessened in proportion to the flux and the time during which it continues.   Under the assumption

of such a susceptibility the fixation of the variation of response is a plain enough matter. The direct path from S_a to M_a is made up (in the diagram of Figure 28) of three units of length, the path from S_a to M_b of five units. The reduction of the resistance of the latter path need not be by any means enormous, in order to make the flux in the direction of M_a so weak as to be practically insignificant.

Substitution of a direct for a devious nervous path. Nervous tension inducing growth. Automatic action. Periodic levels of learning. Two meanings of forgetting. Positive and negative susceptibility of neurons. The curves of learning and forgetting.

THERE is, concerning the fixation of a new path, a very important problem still left. We have reason to believe that in addition to the fixation just mentioned, there is another kind of fixation. Consider this example. When we ask an educated person what six times seven is, the answer is forty-two. When we ask him what six times seventy-seven is, the answer is four hundred and sixty two. Either answer will doubtless be given with the same definiteness and correctness. But there is a great difference in the promptness. While the first answer is enounced directly, the second is enounced only after a considerable delay. The explanation seems obvious. Either path is somehow fixed, but the former, because of the promptness of the response, seems to be much shorter than the latter. As we have just seen, a new path resulting from a variation by deflection is naturally a relatively long path, since the possibility of variation depends on the mediation of centers higher than those of the path to be varied. The fixation of the new path in the manner described does not

change its length and can not, therefore, change the time interval between the stimulation and the response,—the so-called reaction time. Thus, there must be a second kind of fixation of a path, which implies a shortening of the path. We can explain this by the aid of a comparatively simple hypothesis. This hypothesis must be the assumption of a property of the nervous system which permits the growth of neurons in places where there were previously none, and thus the shortening of a long path by *substituting a direct path* for a devious and round-about one. The neurological facts known, point indeed in the direction of such an assumption.

All growth of living tissues, alike in the vegetable and animal world, is of either one or the other kind, by cell division or by growth of the individual cells. Different kinds of tissues, however, show a remarkable difference with respect to these two kinds of growth at the different ages of an animal. In certain tissues, cell division can occur all through life. The necessity of this in certain tissues is clear, for example, in those tissues of which our skin consists. When we have received a considerable wound, involving the loss of some skin, the cells at the edges of the wound divide. The resulting new cells increase in size and divide again; and so on until the opening is completely covered with new skin. Without cell division any new skin could hardly be formed, since there is a limit to the size which individual cells may normally attain. But scarcely any animal goes through life without frequently receiving wounds. In other tissues cell division becomes impossible after the animal has reached a certain age. Since the muscles are of special significance for animal behavior, let us take the muscles as an example. It seems that in human muscles cell division becomes impossible after the age of from twenty to twenty-

five years. From this follows the important fact that, in order to become an athlete, a person must exercise his muscles and thus induce both cell division and cell growth before the age of twenty-five years at the latest. If he has failed to do this, the number of muscle cells which he possesses is so small that exercise, because of the limited growth of the individual cells, will now only slightly increase the bulk and therefore the total strength of his muscles. This age limit for cell division differs in tissues of various kinds.

The bulk of the nervous system consists of nervous tissue proper, that is, the conducting tissue, and of supporing tissue. In the latter, cell division may occur at any age. In the nervous tissue proper, however, cell division, that is the multiplication of neurons, stops before man begins his postnatal life. It has been found that about three months before birth man has as many neurons as he will ever have in his life. At this time, however, the vast majority of these neurons are in the undeveloped condition which we have already described. They are little balls without any branches and therefore of little value for the conduction of any excitation. They develop into complete conductors at various times during life. Some develop early, in order to serve those muscular activities which the baby needs immediately on entering into life, for example, the activities of sucking and swallowing. Others develop during the succeeding years of childhood and youth. It is a peculiar fact, however, that even in old age there are still many undeveloped neurons present in the human brain. The conclusion offers itself that these undeveloped neurons enable their owner to acquire, even at an advanced age, certain new nervous functions. The numerical possibility that such undeveloped neurons will always, to the time of death, be

present and ready to take service, appears from the fact that the total number of neurons in the human brain is enormous, uncountable. They have been estimated at from three to four thousand millions. How long would it take us to count so high, if it took but a second to pronounce each successive number? A day of twenty-four hours contains 86,400 seconds, a hundred years only $3153\frac{3}{5}$ million seconds. We could not do the counting in a life time. Thus it does not matter much if we take a few millions of undeveloped neurons with us into the grave, provided that we are thus at any time of our life capable of new adaptations, of new useful habits. Capable also of regaining nervous functions which we have lost in consequence of a lesion within our brain,—say, a bullet having passed through our brain. In such a case, if we are lucky enough to remain alive, we are found to be incapable of performing certain skilful movements and of reacting in any way to certain stimulations. If a piece of our brain is destroyed, it does not regenerate like a piece of our skin. Its room is filled out with supporting tissue, but the nervous tissue proper, the neurons lost, are lost forever. The functions lost, however, may be entirely or partly regained, just as if they were new habits.

We found it necessary to assume that a new nervous path, a variation by deflection, may first be fixed in its original length and later greatly shortened. We can now explain how this shortening fixation can come about. Suppose a new habit is being formed by the variation of a path, leading now, instead of to the point M_p which corresponds to S_p (Figure 29), by way of a higher center to a non-corresponding point, say M_q. S_p and M_q are supposed to belong to two reflex arches which are very remotely connected, over central sensory and central motor points of a very high order, so that the

resulting path is of a very round-about and zigzag nature.
Figure 29 may be regarded as diagrammatically represent-
ing this path, without, however, suggesting that the path in
the brain would actually present itself to the eye as a
symmetrical figure like this. What is important in the
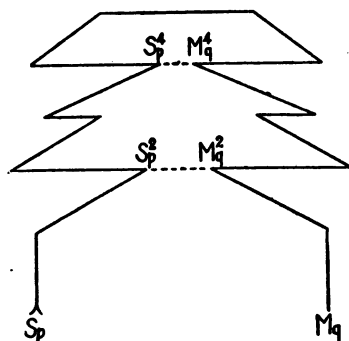
Fig. 29—Automatic action: Short-circuiting in the nervous system.

diagram is only that in various places, for example, at
S_p^4, two points of the path are by chance very near each
other. Let us assume that in such a case we have between
the two points a peculiar, *growth inducing*, biological
condition, just as we should have, if the path were a
metallic conductor carrying a high potential current, an
electrical *tension* likely to break through the insulating
substance in sparks. This simple hypothesis is sufficient
to explain the second kind of fixation of the variation of
a nervous path. The biological tension, so to speak,
between S_p^4 and M_q^4 causes one or more of the undeveloped
nerve cells to grow and send out branches in either direction
of the tension. The consequence of this development
of a new connecting neuron is a shortening of the path
leading from S_p to M_q by practically putting out of func-
tion the part above $S_p^4\ M_q^4$, owing to the higher resistance

of this upper loop. The result of the new growth is that the response at M_q to stimulation of S_p occurs with greater quickness and also with greater definiteness, exclusiveness, for less of the flux from S_p can now reach motor points other than M_q.

The same kind of shortening of the path may occur later between S_p^2 and M_q^2. Here again the biological tension may cause the development of a new connecting neuron out of an undeveloped nerve cell. The length of the total path leading from S_p to M_q may thus be reduced to almost that of a reflex arch. The response at M_q to a stimulus at S_p must then occur with the same quickness and definiteness as a reflex. That habits can become very much like reflexes is well known. In the drilling of a soldier good examples can be found by any observer. Action of this kind is called automatic. It scarcely differs from reflex action in any respect, save in its origin, which is not hereditary. Its resemblance to reflex action is illustrated also by the resistance which automatic action offers to the destructive influences of certain diseases of the brain. When a nervous disease has made a man's actions entirely illogical, certain automatic actions still occur with the same promptness as most reflexes, for example, oaths—in people who have acquired the habit of swearing in early life. This indicates the probability that our hypothesis agrees with what actually occurs in the brain. Since the disease attacks the higher centres of the brain before the lower centres, the development of automatic action seems to consist in the functional cutting out of higher centres from the path, as explained in the diagram of Figure 29.

If the distance between S_p^2 and M_q^2 had been less than between S_p^4 and M_q^4, the shortening of the path might immediately have occurred here. This possibility agrees

with the observation that habitual reactions whose per-
formance at first requires a considerable reaction time,
are sometimes made quicker only in numerous stages, some-
times become completely automatic almost at one time.
Our whole view concerning the shortening of a newly
acquired nervous path is thus supported by innumerable
experimental studies in the acquisition of skill, for example,
in typewriting or in telegraphing.   If the growing efficiency
of a person learning to write on the machine is represented
in a curve, we do not obtain a constantly rising curve,
but one which rises to a certain level, remains on this level
for some time, rises to a higher level, remains on it for some
time, and so on, as illustrated in Figure 30.   Such an im-
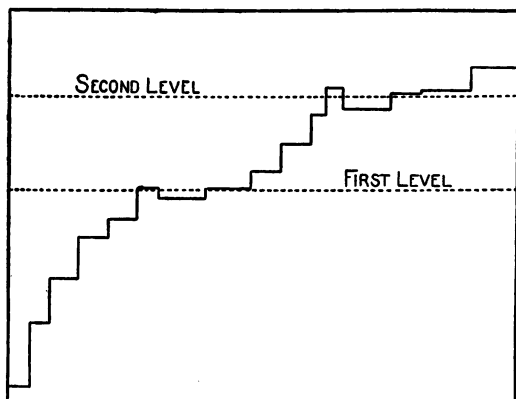
Fig. 30—Steps in acquiring skill: Periodic levels of learning.

provement by steps is to be expected if the fixation of the
variation of response is not merely a fixation of the new
path over higher centers, but at the same time a repeated
shortening by cutting off loops from the original winding
path.   Each time when a loop is cut off, the test of the
person's efficiency must reveal a rather sudden improve-

ment. After this improvement, however, the efficiency cannot but remain practically stationary, until another neuron, perfecting its development, cuts off another loop and thus raises the efficiency rather suddenly again to a higher level.

Let us return to what we called the susceptibility of the neurons. On it is based every possibility of a variation of the nervous path, that is, every possibility of learning. We know that the opposite of learning, forgetting, is of as much consequence in actual life as learning. If we call forgetting the opposite of learning, we should do so in only one sense, namely, in so far as a path, instead of becoming fixed, is being obliterated. In another sense the opposite of learning, of a new reaction more useful than the old, is a new reaction less adapted to our needs than the old, as when we "forget" to lock the door in leaving our house. This, obviously, is a case of inhibition, of nervous deflection, rather than of true forgetting. In so far as obliteration is opposed to fixation we are inclined to explain obliteration by a property of the neurons similar, but opposite to that on which fixation is based. We might speak of a negative as well as of a positive susceptibility. We said previously that the susceptibility of nervous conductors consists in their resistance being reduced by a flux occurring in them, and added that the re-duced resistance of any nervous conductor very slowly rises again to its original measure. The reduction may be called *positive susceptibilty* since it is a reaction to function, the rise *negative susceptibility* since it is a reaction to a lack of function.

In accordance with our statements thus far, the magni-tude of the positive susceptibilty must be determined by two factors, the intensity of the nervous process and its duration. In the analogous case the river bed is washed

out the more, (1) the more water flows through it
in a unit of time, and (2) the longer this flow continues.
On the other hand, the negative susceptibility depends
only on one factor, the time during which no ner-
vous process occurs in the neuron. It is interesting,
therefore, to compare the quantitative results of experi-
mental studies of the progress of learning, which is the
effect of the positive susceptibility, with those of the prog-
ress of forgetting, which is the effect of the negative
susceptibility.

The increasing efficiency of reaction in the process of
learning is always represented by a curve like that of
Figure 31, rising first rapidly, then more and more slowly,
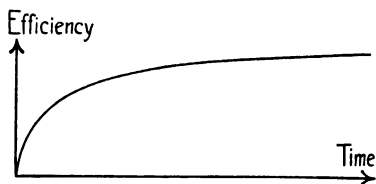
Fig. 31—Learning dependent on time.

provided that we have in mind one continuous process
without any intervening periods of rest. In a longer
process of learning spreading over days or months, and
containing many extended periods of rest, the efficiency
rises, as we have seen, in the manner of Figure 30.
We notice that in a continuous process of learning, lasting
say, half an hour, the first few minutes are the most
valuable. During the following minutes less and less
is gained in efficiency, and the last few minutes add so
little to the result that we might just as well have stopped
earlier. This fact is established beyond doubt by experi-
ment and agrees also with the ordinary experience of
any one who has to practice anything, for example, the

school-boy memorizing a foreign vocabulary. To read over the whole task five minutes a day for a sufficient number of days to complete it, is much more economical with regard to the total time required, than to complete the task in one continuous memorizing. If we continue the process only for five minutes, we do not make use of the uneconomical part of the time curve farther to the right in the figure. At first glance, the facts represented in this curve seem to overthrow our analogies. Why should a flux, broadening and deepening its channel, do this the longer the less? But the matter becomes clear when we remember that in a neuron, with its limited resources, the flux cannot remain continuously on the same level of intensity. The neuron does not become less and less susceptible to the flux, but the flux becomes in spite of an undiminished intensity of stimulation less and less intensive. The total result, then, must be in accordance with Figure 31.
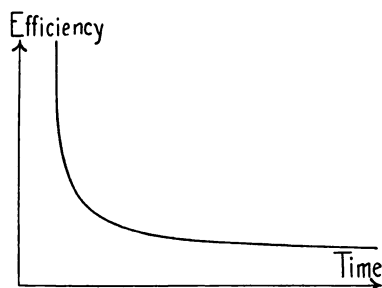
Efficiency

Time

Fig. 32—Forgetting dependent on time.

The decreasing efficiency of reaction in *forgetting* is represented by a curve like that of Figure 32. This agrees well with our analogies. We compared the negative susceptibility with the fate of a river bed through which no water flows any more, and which is gradually obliterated

by being filled with debris and dust. Such a filling in is usually very pronounced at first, when the banks of the river bed are still steep, less and less considerable later, so that traces of the original depression of the ground may continue for an exceedingly long period. Although the analogy is remote, it shows that the curve may well be expected to have the shape of Figure 32.

This curve, however, of Figure 32 does not indicate what changes, if any, the efficiency undergoes during the time directly following the period of practise, during the first few seconds or minutes, let us say. Now, it is a matter of common experience, that anything we have just learned stays with us, as a rule, for a few minutes
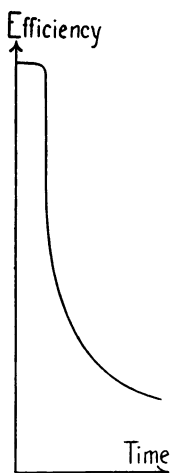
Fig. 33—Forgetting immediately after practice.

with hardly lessened efficacy and is only then forgotten at a rapid rate. Perhaps the complete curve ought to be drawn as it appears in Figure 33, remaining almost on a level for a short time, then falling very quickly and

later falling more and more slowly. The usual experiments concerning the rate of forgetting do not tell anything about the first few minutes since they are made only with the intention of recording the loss from day to day. But the ordinary experience is in this case definite and general enough to assume that the loss during the very first few minutes—not to speak of seconds—is practically nothing. Let us here record the fact without attempting to explain it.

NINTH LECTURE

Sensory condensation in piano playing. Proportional reduction of the resistance of higher and lower centers connecting the same corresponding points. The positive (and negative) susceptibility of a higher center greater than that of a lower center. Motor condensation in grasping.

WE have studied and explained in detail one of the three kinds of variation of the nervous path, the simple variation of response. Let us study next that kind which we called sensory condensation. Musical practise may serve as an example. A child learning to play the piano, at a certain place in his piece, wants to strike two keys without having to look at both the corresponding notes in the score—no matter whether looking at both is possible or, because of their distance apart in the score, impossible. He begins by looking at one of the notes, seeing, let us say, the other one in indirect vision and therefore indistinctly. He reacts to the former by a perfectly definite finger stroke. But the other note, not clearly separated from its surroundings by the perceiving eye, calls forth an incorrect or insufficient movement. The child tries again, and now, of course, looks at the note whose movement was not properly executed. Everything is reversed. The finger movement which was previously done badly is now done well, and the movement which was previously done well

is done badly. After many trials, on the whole alternating as to the note favored by the eye, and as to the finger crowned by success, the child becomes able to perform both movements simultaneously with equal definiteness although he is looking at only one of the notes—no matter which one he is looking at. How do we explain this process of sensory condensation?

In order to explain it we make use of a diagram very similar to that of Figure 28, which helped us to explain the simple variation of a child learning to avoid contact with fire. For simplicity's sake, we represent the stimulation by the note looked at as a single strong nervous process taking its origin from S_b (in Figure 34), and the stimulation
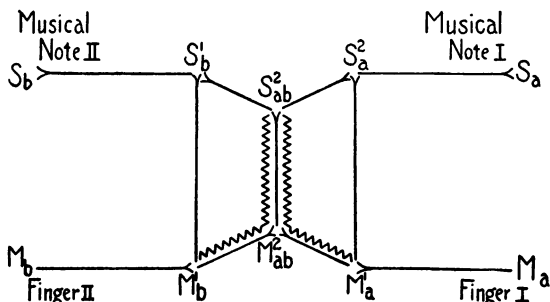
Fig. 34—Sensory condensation explained.

by the note seen indirectly as a single weak nervous process taking its origin from S_a. We learned from Figure 28 that the motor response to this double stimulation, strong at S_b and weak at S_a, occurs only at M_b. In the child's second trial everything is reversed. The stronger process is the one starting from S_a and the weaker the one starting from S_b, so that the motor response occurs only at M_a. This goes on, the motor response occurring alternately at M_b and M_a. The question is what kind of changes the resistances of the various neurons undergo.

Plainly, when S_a and S_b are stimulated for the first time simultaneously and the motor response occurs at the point M_b (see Figure 28), the neurons $S_{ab}^2 M_{ab}^2$ and $M_{ab}^2 M_b^1$ suffer a slightly greater reduction of their resistances than in case S_b is stimulated alone. But it does not make any difference to the reduction of the resistance of the neuron $S_b^1 M_b^1$, whether S_b is stimulated alone or S_a too. The flux from S_b divides at the point S_b^1 and goes on to M_b^1 partly over the direct, partly over the indirect route. Let us assume for the present, quite arbitrarily (we shall soon discuss this assumption separately), that the *relative* resistance of each of the four neurons $S_b^1 M_b^1$, $S_b^1 S_{ab}^2$, $S_{ab}^2 M_{ab}^2$, $M_{ab}^2 M_b^1$ in case the flux comes exclusively from the sensory point S_b, remains absolutely constant, so that none of these neurons is then in any respect favorably influenced, compared with the other three. When, however, S_a is stimulated at the same time with S_b, two of these four neurons are, with respect to the reduction of their resistances in consequence of their positive susceptibility undoubtedly in a more favorable position than the other two. The favored ones, $S_{ab}^2 M_{ab}^2$ and $M_{ab}^2 M_b^1$, in which occurs the additional flux deflected from the reflex arch $S_a M_a$, are marked in Figure 34 by a zigzag line. Soon, as we have seen in our example of the piano-playing child, the reverse stimulation occurs. S_a is now stimulated strongly, S_b at the same time more weakly. Of the four neurons $S_a^1 M_a^1$, $S_a^1 S_{ab}^2$, $S_{ab}^2 M_{ab}^2$, and $M_{ab}^2 M_a^1$, two are now with respect to the reduction of their resistance specially favored, namely $S_{ab}^2 M_{ab}^2$ and $M_{ab}^2 M_a^1$. They are marked in Figure 34 in the same way by a zigzag line. If these two events happen *alternately* (this is the important condition, without which the outcome would be a mere variation of response) in a sufficient number of repetitions, the final result can be read off

from the diagram of Figure 34. The relative resistances will be gradually changed so that ultimately any flux starting from either S_a or S_b exclusively, will take, in the main, the path over $S^2_{ab}M^2_{ab}$, divide at the point M^2_{ab} almost equally, and cause a response at M_a as well as at M_b (a striking of both the piano keys),—practically as if neither the neuron $S^1_aM^1_a$ nor $S^1_bM^1_b$ were any longer in existence.

Thus this kind of a variation of the nervous path—sensory condensation—would have been explained, but only under the assumption just made that the *relative resistance* of any *higher nerve center* connecting the same corresponding points (for example S_b and M_b) as any *lower nerve center* remains constant, however much the absolute resistance of all these centers may be reduced by a continuation or repetition of an isolated stimulation of the sensory point in question. This is the same assumption, only generalized, which we made with regard to four special neurons, and upon which we based our reasoning in the explanation of sensory condensation. This assumption is by no means self-evident. On the contrary, one might expect something very different. If S_b alone is stimulated, the flux in the neuron $S^1_bM^1_b$ must be about three times as strong as in any of the neurons $S^1_bS^2_{ab}$, $S^2_{ab}M^2_{ab}$, and $M^2_{ab}M^1_b$, since the path from S^1_b to M^1_b over these three neurons in series offers a greater resistance than the direct path over the single neuron $S^1_bM^1_b$. In consequence of the greater flux, the resistance of the neuron $S^1_bM^1_b$ might be expected to be reduced, by and by, relatively much more than the total resistance of the other three neurons is reduced.

This last consequence, however, is biologically impossible. It would mean, in this special case, that the resistance of the neuron $S^1_bM^1_b$ would tend to become so much reduced in comparison with any other nervous connection

between the points S_b^1 and M_b^1, that the reflex arch
would be practically separated from its connection with
the points S_{ab}^2 and M_{ab}^2. In general terms it would
mean that all the reflex arches tend to become functionally
separated from the higher nerve centers. Why
should any animal have higher nerve centers, if the
natural tendency of any nervous function from the
beginning of individual life were to make the conduction
of excitations over any higher centers more and more
difficult and even impossible? The animal, then, might
just as well, from the beginning of its life, possess no
nervous conductors whatsoever, other than the reflex
arches. It is clear, then, that we have, on quite general
biological grounds, the right to assume that the relative
resistance of any higher nerve centre connecting the same
corresponding points as any lower nerve centre, in the
case of isolated stimulation of the sensory point, remains
constant. That is, in our special case (Figure 34), we
have the right to assume, as we did, that when S_b alone
has been stimulated, and the flux has occurred, in accor-
dance with the length of the conductors, more strongly
over S_b^1 and M_b^1 directly, more weakly over S_{ab}^2 and M_{ab}^2,
the ratio of the resistances of any two of the four connec-
ting neurons involved always remains identical. Only
simultaneous stimulation of a second sensory point can
bring about a change of the relative resistances,—favoring
the one or the other according to the special circumstances
of the case. Our explanation of this case of sensory
condensation is therefore complete.

The assumption made concerning higher and lower cen-
ters, which we found necessary on general biological
grounds, may be stated also in different words. If the
lower nerve center (take as an example the connecting
neuron $S_b^1 M_b^1$ in Figure 34) does not, in spite of the

greater flux within it, suffer any greater reduction of its resistance than the higher center $(S_b^1 S_{ab}^2 M_{ab}^2 M_b^1)$, the positive susceptibility of the lower center is obviously less than the positive susceptibility of the higher center.

If this holds good for the positive susceptibility, we have reason to ask if it applies also to the negative susceptibility. That it does, seems to follow from the familiar fact that any ability is lost through the normal process of forgetting the less readily, the greater the number of instinctive, low-centered relations contained in it. For example, we forget how to recite historical dates more easily than we forget how to skate. Perhaps, then, we are justified in stating the assumption quite generally thus: *The neurons of higher centers have a greater susceptibility than those of lower centers.*

We have still to explain the third kind of variation of the nervous path,—that kind which we called motor condensation. The condensation of the motor activity can be explained in practically the same way as a variation of response. We have learned from Figure 28 that, when S_a is rarely stimulated alone, but frequently together with S_b and then less strongly than S_b, the path leading from S_a to M_b tends to offer less and less resistance and finally to surpass greatly in conductivity the path from S_a to M_a. It is plain that when this stage of development has been reached, simultaneous stimulation of S_a and S_b can scarcely under any condition of relative intensity result in a simultaneous response at both the motor points M_a and M_b, but exclusively in a response at M_b.

But not all cases of learning which deserve the name of motor condensation are so simple. Let us take as a concrete and not too complicated example the baby who, during several months, can grasp small articles only by closing

his whole hand, but afterwards learns to grasp a small article, for example a shirt button, between his thumb and index finger, like a grown person. At the sight of a sufficiently conspicuous object the young baby stretches out his arm. As a consequence of this reflex movement the fingers are stimulated by *contact* with the object. When the tip or any other part of the *inner surface* (from the nail toward the palm of the hand) of any finger is stimulated by touch, the finger *reflexly bends*. After a few months the baby learns to respond to the mere sight of an object by the initial part of the movement of closing the hand; that is, the fingers begin to bend while the arm is still being stretched out, before they have had any contact with the object. What gives, at this stage, the grasping a particular appearance of clumsiness is the fact that the thumb does not aid in grasping, but is left practically functionless. To understand this is not difficult if we recall the statement just made that the original (reflex) bending of any finger results from touch stimulation of its inner surface. When the arm is stretched out and the hand naturally *drops* on the object presented, the thumb is not stimulated, as the other four

Fig. 35—Thumb and finger movement.

fingers are, on its inner surface, but on its side. This is the natural consequence of the anatomical location of the thumb, which moves, as the arrow in Figure 35 indicates, in the plane vertical to the plane of movement of the other fingers. Accordingly, the thumb has a less strong tendency to bend reflexly and, after the other fingers have bent, is prevented by them from bending.

Compare with this clumsy manner of grasping the skill which the same child shows less than a year later, in taking hold of a small object. While the arm is being stretched out, in response to the sight of the thing, the thumb and the index finger assume positions opposite each other, ready to take the object between them. The other three fingers remain all the time at rest, in whatever position they happened to be at the start. If the object is of medium size, the middle finger assists the index finger. Only if the object is large, do all the four fingers come into action. In any case the thumb assumes a position opposite the fingers while the hand is still approaching the object, that is, in response to the mere sight of the object.

This whole process of learning can be made clear by the aid of a comparatively simple diagram. S_a represents, in Figure 36, the eye. The neurons $S_a^1 M_a^1$ and $M_{ab}^2 M_a^1$ leading toward the motor organ which stretches the index finger, are marked as not yet developed. The shortest motor outlet from S_a is therefore M_b, the motor organ stretching the arm. In consequence of this stretching of the arm, the points S_d, S_e, S_f, and S_g, representing the finger tips, are stimulated. The reflex response at M_d, M_e, M_f, and M_g is a bending of the four fingers and enclosing the object by them. The nervous processes from S_d, S_e, S_f, and S_g attract, by dint of their own intensity, the process coming from S_a and force it to take largely the path over $S_{ab}^2 S_{abcdefg}^3 M_{abcdefg}^3 M_{cdefg}^2$ and thence into M_d, M_e, M_f, and M_g. The resistance of this path decreases until, after repeated occurrence of this deflection and the fixation of the path, the excitation caused at some time at S_a travels in the direction of M_d, M_e, M_f, and M_g and causes the beginning of a bending even before any of the finger tips have been touched.
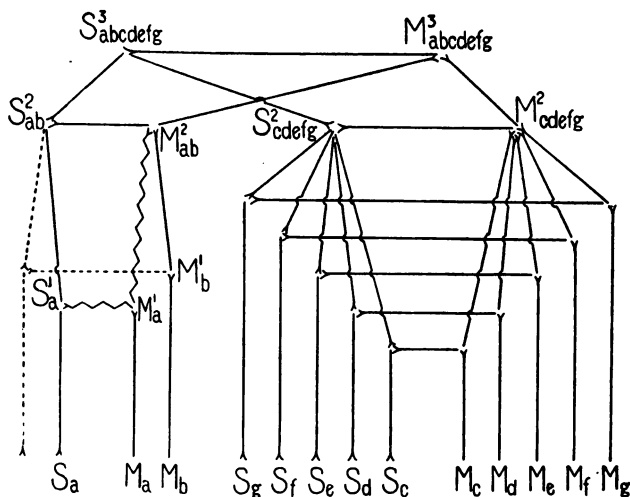
Fig. 36—Learning how to grasp.

S_a, Eye—M_a, Stretching index finger—M_b, Stretching arm—S_c,
Tip of thumb—S_d, Tip of index finger—M_c, Bending thumb—M_d,
Bending index finger—*Zigzag*, Neurons undeveloped at birth.

This accomplishment becomes the subject of a new
influence at some time during the second half of the first
year. The neurons marked in Figure 36 by zigzag lines
reach by this time their full development and establish
a new hereditary connection. When now the eye is
stimulated, not only the arm but also the index finger is
stretched out. This reflex appears at about the same time
that the first articulated sounds (usually dental and
guttural—"da" and "ga") are instinctively enounced by
the baby,—a coincidence the significance of which we shall
discuss at a later time. The result of this stretching of
the index finger, with the other fingers in their ordinary
slightly bent position, is touch stimulation of the tip
of the index finger exclusively. Since the other fingers
remain unstimulated, the index finger alone bends. If the

object is small, this bending movement of the index finger touching it is likely to pull the object toward the hand. When this is actually done, the object comes into contact with the outer surface of the other fingers and the inner surface of the thumb. The former contact is irrelevant, because it occurs on the outer surface; but the contact with the thumb is followed by a reflex bending of the thumb, so that the object is squeezed between the thumb and index finger. This means, in the diagram of Figure 36, that the two nervous processes from S_c to M_c and from S_d to M_d deflect the nervous process coming from S_a by dint of their greater intensity and force it to take the path over $S^3_{abcdefg}$, $M^3_{abcdefg}$, and M^2_{cdefg} into M_c and M_d. If this whole occurrence happens repeatedly, the resistance of the path from S_a into M_c and into M_d is so much lowered that finally, at the appearance of the object, the excitation travels not only to M_a and to M_b, but largely also to M_c and M_d and causes a motor response here too, although slightly later than at M_a and M_b because of the difference of the distance. This makes it plain, why toward the end of the first year the child responds to the mere sight of an object by stretching out his arm and at the same time making the thumb and index finger ready to receive the thing which has been presented to the eye. The motor expansion, the clumsy use of the whole hand, has been succeeded by the motor condensation, the use of two fingers only.

TENTH LECTURE

Order of acquisition of the first four classes of habits. Control of the sense organs of the head. Direction and extent of the fixation movement of the eye. Improvement by experience of the fixation movement of the eye. A variation of response resulting from a close succession of nervous processes just as from a deflection of one by another. Coordination of the eyes. How an infant learns to face a sounding object. Control of the hands and arms. Learning to raise the arm in response to a visual object above the eyes. Loose co-ordination of eye and hand.

WE have considered the change of behavior, which we call learning, in its positive as well as in its negative aspect. We have recognized that learning and unlearning (inhibition) are only the positive and the negative aspect of the same nervous function. We have further convinced ourselves that the three classes of change of behavior, which seem to include all possible kinds, variation of response, sensory condensation, and motor condensation, are at bottom the same nervous function, which in its simplest form we have called variation of response. The above explanation of this nervous function, however, is applicable only in case one nervous process which influences another, begins before the other has ceased, that is, in case of simultaneity. Learning as applied to successive nervous processes will be explained farther below. We shall

first make ourselves acquainted with the most fundamental reflex activities of childhood from which human learning develops. The study of this development will show us in what respects the explanations of human behavior given thus far are sufficient and in what respects they need to be supplemented.

Childhood is the very age of learning in human life. Great as the accomplishments of human beings may appear which are acquired in schools and colleges, they are as a matter of fact small when compared with those of the first six or seven years, before the individual is systematically trained by his teachers. It is of the utmost importance for the teacher to understand how learning proceeds before it is systematically directed, in order to avoid the forcing of the individual into an educational system which is unrelated—or even opposed—to the natural way in which man acquires his habits in early childhood. The first habits acquired by the baby are those connected with the use of the sense organs of the head. Then the baby learns to use his arms and hands. Toward the end of the first year or soon thereafter he learns to use his feet for walking and running, and toward the end of the second year to use his vocal organs for speech. Of course, we do not mean that each one of these classes of activities must become perfect before the next begins, but merely that they usually become conspicuous in this order. Besides, it is well to keep in mind that individual differences are exceedingly common, so that these four stages of development are not in every child equally obvious.

Of the sense organs of the head, the eyes are those whose efficient use depends most on proper motor adjustments, —much more so than the ears or the sense organs of the mouth. The chief reflex of the eye consists in a turning of

the center of the eye, the "fovea," the area of most
distinct vision, in the direction of the most effective
object of visual stimulation, in a "movement of fixation"
as we may call it.   It is quite natural that this response
at first is often rather inadequate in accuracy of direction
and particularly of extent,—the center of the eye moves
either beyond the point where it could receive the optical
rays from the object in question or not far enough to
reach this point.   Gradually, however, the movement
becomes more and more adequate.   Yet it never becomes
absolutely exact even in adult life.   Even the grown
person, in order to fixate an object, must, practically
without exception, correct the first sweeping movement
of fixation by smaller ones before a sufficiently accurate
adjustment of the fovea is obtained.   Figure 37 gives an
example of a complex eye movement of this kind, the
first sweep of the object's image being from S_a to S_b.

Fig. 37—Fixation movement of the eye.
On Retina: F, Fovea—S_a, Point stimulated before fixation movement—
     S_b, Point stimulated after fixation movement.
On Field of Vision: F, Point to be fixated—S_a, Point fixated before
     movement—S_b, Point fixated after movement.

Two things need explanation.   First: why the eye ball
moves always in the direction of the stimulus.   Secondly:
why the eye ball stops at the moment when the fovea is
approximately opposite the stimulus.   The first is easily
explained.   The various sensory points of the retina are
doubtless connected with the eye muscles by reflex arches
in such a way that, when any point of the retina is especial-
ly stimulated, the excitation takes its path toward those
muscles or groups of muscles which pull the eye in the

proper direction.   In this respect no learning is necessary.
The *direction* is determined reflexly.   The second question
is less easily answered.   Why does the eye movement stop
as soon as the fovea has approximately reached a point
opposite the object?   One feels inclined to think that
during the fixation movement of the eye the object,
suddenly striking with its rays the fovea, sets up there a
particularly effective excitation which either results reflexly
in a muscular contraction capable of fixing the eye in
the position just reached, or stops the movement by
inhibiting the nervous process which causes it.   Such
explanations could still be offered as recently as ten years
ago.   But the research of the most recent years has dis-
credited them.   For some reason or other sensory excita-
tions received while the eye moves, fail to become effective
and, therefore, can not in any way stop the movement.
The *extent* of the sweeping movement of the eye must also
be determined reflexly and in advance of the motion—
probably by a *strong* excitation reaching the muscles which
pull the fovea in the proper direction *and* a relatively
weak excitation reaching the antagonistic muscles.   If the
inherited connections of every point of the retina with
the various groups of muscles are such as to determine
through their resistances a definite ratio of the two anta-
gonistic muscular effects just mentioned, the eye must
clearly stop at a definite point,—where the antagonistic
motor effects balance each other.   Figure 38, for clearness'
sake, suggests how the nervous conductors might be
arranged in order to bring about this result; but we do
not, of course, assert that they are arranged just in this
way.   The figure contains only two motor points, M_L and
M_R, representing, say, the muscles which pull the eye to
the left and those which pull to the right.   The sensory
points represent a series from one side of the retina, at
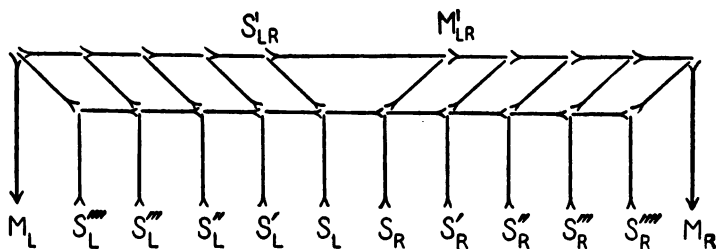
Fig. 38—Simultaneous innervation of antagonistic muscles.

S_L'''', (the right side, opposite the left edge of the field of vision) to the other side, at S_R''''. It is evident that a nervous process starting, for example, from S_L'' must go mainly to M_L, traveling thus over the smallest number of neurons possible; but a considerable fraction of it must pass over $S_{LR}^1 M_{LR}^1$ to M_R. A nervous process starting, for comparison, from S_L' can send only a smaller part of its total flux to M_L, since the resistance of the path from S_L' to M_L is greater than that of the path of fewer neurons from S_L'' to M_L : so a larger fraction of the flux takes the now shorter path over $S_{LR}^1 M_{LR}^1$ to M_R. The farther we go to the sensory points at the right of the figure, the more we find M_R favored in comparison with M_L. Thus the eye must come to a standstill at different angles according to the sensory point excited and the corresponding ratio of the excitation of the antagonistic muscle groups.

This is simple enough thus far. However, this ratio does not seem to be established by inheritance with any great exactness, so that there is still left the problem which is of special interest to us in this study, namely, how we can explain the great *improvement* in the accuracy of the fixation movement which is to be observed during the first weeks and months of life,—how the child *learns* to execute these sweeping fixation movements with so much more accuracy in direction and extent after a few months

of experience.   The very purpose of our present study is, not to take *learning* as a phenomenon which is too common to need explanation, but to arouse our curiosity about it and to satisfy this by making the process of learning as plain as the running of a steam locomotive.

We may restrict our discussion to the *extent* of the movement stopping at, or before, or beyond a certain point, but always on the straight line passing through it. A movement along a line leaving the point to be fixated more or less at one side, is obviously simply the component, geometrically, of two movements, two muscular effects, and does not involve any additional principle of explanation.   We shall, then, have to solve the following typical problem: If in earliest childhood, the fixation movement brings the image, let us say, from S_a, in Figure 37, to S_b, some distance beyond the fovea, *why* is it that after some experience the sweep is so much shorter that the image is brought from S_a to the nearest neighborhood of the fovea?

Figure 39 will aid us in understanding how the fixation movement of the eye can be improved by experience— in understanding, at the same time, what the often mysterious word "experience" really signifies. S_a represents the sensory point where the image of the object first appears on the retina, M_a the motor point which signifies pulling the fovea in the direction of the optical image. M_b represents the motor point which signifies pulling the fovea in exactly the opposite direction.   In order to bring about the proper movement of approximately the right extent, both M_a and M_b must be excited,—but M_a more strongly (if equally, there would be no movement at all), M_b only strongly enough to bring the eye ball after some time to a standstill, through the balancing of the opposite forces of muscular tension.   The antagonistic muscles,

in such a case, must act upon the eye ball in the same way
in which two rubber bands of different tension, attached
to and pulling, say, a piece of cork in opposite directions,
would act. We have assumed that the tension resulting
from M_a is relatively too great, so that the image, instead
of falling upon the fovea, now falls at a point S_b, some-
what beyond the fovea. It is easy to understand from
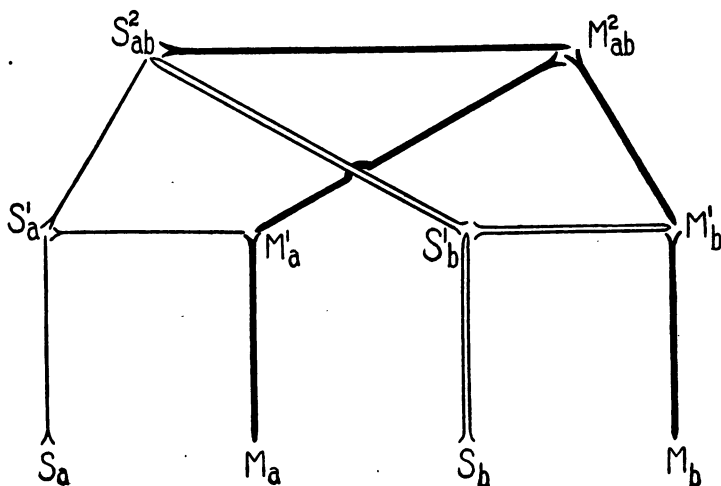
Fig. 39—Improvement of the fixation movement of the eye.

Figure 39 why stimulation of S_a should result in a stronger
excitation at M_a and a weaker one at M_b. But why
should, at a later recurrence of the stimulation of S_a,
after the "experience" has become effective, the excita-
tion at M_b be relatively greater, thus balancing the effect
of M_a sooner and preventing the fovea from moving as
far as the first time, stopping it nearer the correct point
of fixation, the point F in Figure 37? The answer to this
question is the solution of our problem.

In order to give the answer, we must consider the correcting movement. As soon as the eye stops after having swept too far, S_b is stimulated by the new optical impression, and—everything being exactly reversed—the fovea is pulled in the opposite direction. Let us see what neurons conduct the excitation whenever S_b is stimulated. They are, eight in number, marked in Figure 39 partly as broad, partly as double lines. A moment ago S_a was stimulated and the excitation took its path over some of these very neurons, namely, over those drawn in broad lines. The effect of that excitation, reducing the resistance of the neurons, lasts for some time before the negative susceptibility begins to restore the former resistance, as discussed previously and illustrated in Figure 33. Therefore, when now S_b is stimulated and the excitation coming from S_b reduces the resistance in all the neurons through which it passes, the resistance of the neurons drawn in broad lines *not merely begins* to be reduced, like the resistance of the neurons drawn in double lines, but is *further reduced*. In the total system of Figure 39, the neurons drawn in broad lines thus suffer a *relatively greater reduction of their conductivity* than all the others. It is easy to see that our problem is herewith solved, for when now at any time the retinal point S_a is again struck by an optical image, a greater fraction than originally of the excitation from S_a can pass over $S_{ab}^2 M_{ab}^2$ and $M_{ab}^2 M_b^1$ into the non-corresponding point M_b, causing a stronger muscular tension at M_b and an *earlier* balancing of the antagonistic forces which bring about the sweeping movement of fixation.

To remove all doubt as to the correctness of this conclusion let us look again at the broad lines of Figure 39. The short route from S_a to M_a consists of three neurons, of which one is favored by the effect in question; that is, *only*

one-third of the total length of the path. The longer route from S_a to M_a and the route from S_a to M_b, however, consist each of five neurons, of which three are favored by the effect in question; that is, as much as *three-fifths* of the path. It is clear that the total result of this widening of one-third of the length of one path and of three-fifths of the length of the other path is to the advantage of M_b, to the disadvantage of M_a. The ordinary superiority in intensity of response (to stimulation of S_a) of M_a over M_b is based on the greater conductivity of the reflex arch $S_a S_a^1 M_a^1 M_a$, which has now been *relatively* diminished. Any relatively greater reduction of the resistance of the higher center $S_{ab}^2 M_{ab}^2$ must favor the ordinarily quite weak response of the non-corresponding point M_b, to the disadvantage of the corresponding point M_a. The motor effect of M_b now balances the effect of M_a a little earlier, brings about the stopping of the eye movement a little earlier. That is, the next fixation movement is more correct.

We see, then, that the improvement of any particular nervous function by "experience" of the individual is an altogether natural phenomenon,—no more mysterious, although different in kind, than the gradual improvement of the draft in a cold chimney after the fire has been burning for some time. A few fundamental laws which we assume as governing nervous activity are sufficient to explain this learning by experience, without any necessary reference to "conscious" experience. The present case is clearly a variation of response, for we have now a relatively strong motor effect where (at M_b in response to a stimulation of S_a) we had originally only a weak part of the total effect. But we notice the important fact that the variation has come about without a deflection of one nervous process by a simultaneous one taking

place.   We see, then, that the same variation which can
be the result of a *deflection,* can also be the consequence
of a *succession of nervous processes,* provided the law
illustrated in Figure 33 is applicable, the law that any
reduction in resistance remains for a short time (a few
seconds at least) uninfluenced by the negative susceptibili-
ty.

We have explained how the improvement of the accur-
acy of the fixation movement comes about, which dimin-
ishes the need for movements of correction succeeding
the first sweep.   Simultaneously another improvement
takes place,—that of the co-operation of the two eyes.
During the first days of a baby's life it may not infre-
quently be observed that the eyes move independently
of each other, that one moves to the right while the other
stands still or moves even to the left.   This is but natural
since a striking object may not impress one eye as strongly
as the other, indeed may be invisible to one eye if it
happens to be near the right or left edge of the total field
of vision.   How, then, is the nervous system "educated"
so that later both eyes always move together to the right
or left, even when the object is, in advance of the move-
ment, invisible to one eye?

In Figure 40, M_l and M_r represent those motor points
whose simultaneous excitations cause the simultaneous
and similar movements of the two eyes.   Whenever S_l
and S_r are stimulated simultaneously and with equal
intensity, as it happens most frequently, the simultaneous
excitations of the two motor points are self-evident.
But why are, after a few months of life of the individual,
the motor points simultaneously excited even when one
of the sensory points is unstimulated?   This is clearly a
case of sensory condensation.   It may be thought to come
about in the following way.

Whenever S_l is stimulated alone, by far the largest part of the excitation takes its path over the reflex arch directly to M_l. A smaller, though considerable, part, however, takes the indirect path over $S_l^2 M_l^2$ and even over $S_{lr}^3 M_{lr}^3$, mostly in the direction of M_l, but to some extent also in other directions, for example, toward M_r.
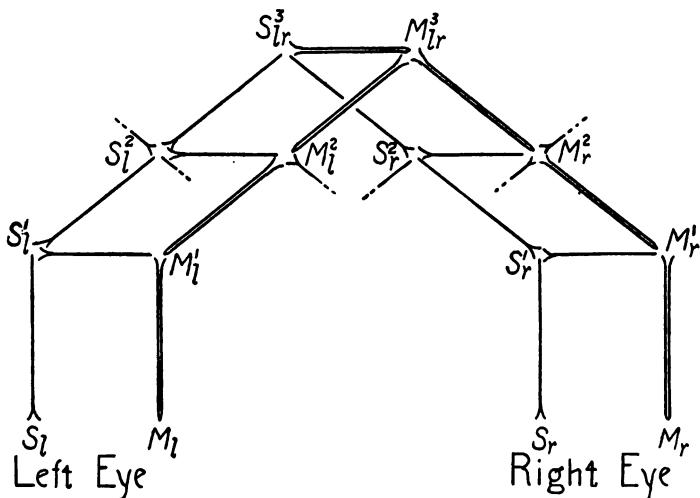
Fig. 40—Co-ordination of the two eyes or any two organs.

Whenever S_r is stimulated alone, by far the largest part of the excitation takes its path over the reflex arch directly to M_r. A smaller, though considerable, part, however, takes the indirect path over $S_r^2 M_r^2$ and even over $S_{lr}^3 M_{lr}^3$, mostly in the direction of M_r, but to some extent also in other directions, for example, toward M_l. In either case, when S_l or S_r is stimulated alone, the relative resistance of the lower and higher neurons involved remains unchanged, in accordance with the law which we assumed in the preceding lecture. But when S_l and S_r are stimu-

lated at the same time, those neurons which belong to the system of S_l as well as to that of S_r are favored over all the others with respect to the reduction of their resistance, since a double excitation—and therefore a stronger flux—passes through them. These neurons are drawn in Figure 40 in double lines. The relatively greater reduction of the resistance of these neurons may amount to but little in a single case of "experience." But it must become quite considerable in a few months, since simultaneous stimulation of both eyes by the same object is naturally a very common occurrence. When the resistance of the double drawn neurons has become much reduced, an ever increasing amount of the flux takes its path, instead of over a reflex arch, over the higher center $S_{lr}^3 M_{lr}^3$, which forms the connecting bridge between the two eyes. Accordingly, an ever increasing part of the flux finds its way from M_{lr}^3 down into M_r even when S_l happens to be stimulated alone, or into M_l when S_r happens to be stimulated alone, until finally the response occurs regularly at *both* M_l and M_r no matter whether both the sensory points are stimulated or only one of them. That is, the movements of the eyes have become perfectly *co-ordinated.*

The co-ordination of the eyes is an example of that kind of variation of the nervous path which we have called sensory condensation. Another example of sensory condensation which we have studied in detail is that of a child learning to execute, on the piano keyboard, two finger movements in response to only one note. The explanation in detail of the two examples is somewhat different owing to the fact that in the former case the sensory condensation results from a two-fold stimulation of unequal intensities, the one and the other sensory point being alternately more strongly excited, whereas in the present case both sensory points are usually stimulated with the same

intensity.   We have thus seen that sensory condensation can result under various circumstances, provided only that the reflex arches involved are connected—and not too remotely—by higher nerve centers.

Next to the eye, the ear is the sense organ of the head which is most interesting because of its motor adjustments. We are naturally inclined to assume that there is here a reflex similar to the turning reflex of the eye,—that, when a sound strikes one of the ears more strongly than the other, the face turns reflexly toward the source of sound. This would mean that, by inheritance, of the muscles turning the head those on either side are more closely connected with the one ear than with the other ear.   The purpose of this head movement would be, not so much a better adjustment of the organ of hearing, as of the organ of sight,—the eyes when facing the source of sound would be more likely to receive from it an effective visual stimulation.   Such a reflex response, however, a turning of the face in the direction of a sound, does not seem to exist. When a child is five to six months old, this response is quite common, but during the first three months it does not occur.   One may, of course, assume that the reflex does not mature until several months after birth, and support this assumption by the fact that some instincts and reflexes mature even years after birth.   However, reflexes whose maturity is undoubtedly delayed—take for example the sexual—are obviously delayed because their appearance directly after birth would be useless. But turning the head in the direction of a sound would not be entirely useless even in earliest infancy.   We may therefore, as long as the question is left undecided by the physiologists and anatomists, regard it as most probable that the turning of the face in the direction of a sound is not a reflex, but a habit which is usually established three

or four months after birth. Our problem, then, is to explain how the individual learns to respond thus to sounds which stimulate the two ears unequally.

There can hardly be any doubt that the habit of turning the face toward a source of sound is a variation of response —one of that kind in which the same response occurs, but another stimulus has been substituted for the original one. The original stimulus is visual. The fixation reflex of the eyes can be observed as functioning a few weeks after birth; and the reflex turning of the head can be seen to support and supplement the eye movement at the same early age,—in response to sight, for reflex movements of the head in response to tactual stimuli occur even a few days after birth, when the baby, held to the mother's breast, hunts, so to speak, for the nipple. Objects which appear in indirect vision and therefore call forth the fixation reflex, are frequently sources of sound,—for example, the mother's face. That is, the baby's ears are stimulated at the same time as the eyes. If the nervous flux coming from the ear more strongly stimulated, and including, by deflection, most of the flux from the other ear, has no particular reflex outlet, it must take its path, other things being equal, mostly in the direction of any other strong nervous process existing at the same time and therefore attracting it. It must take its path in the direction of that motor point which in response to the visual stimulation turns the head to face the source of sound. There is no danger that the reverse might occur, that the nervous flux coming from the eye might be attracted by the flux from the ear, for we are working under the assumption that the flux from the ear has no low-resistance reflex outlet and, therefore, cannot attain any such great intensity as that from the eye. When the deflection from the ear to the head-turning muscles has

occurred often enough and the resistance along this path has been effectively lowered, the habit which we intended to explain is established. The head then turns even in response to a source of sound which may remain permanently invisible. That the habit is not established until several months after birth, is caused probably by the absence, at an earlier time, of connecting neurons which are capable of serving as a chain of conductors. It is a well established fact that the majority of the higher nerve centers capable of serving such remote connections are immature at birth and fairly mature only three months later.

The next large group of activities we proposed to study are those of the hands and arms. We have already seen how, from the reflex of a bending of the fingers in response to a stimulation of their inner surfaces, the delicate and skillful grasping of the older child and of the adult develops. We have also mentioned that the arm is reflexly stretched out in response to a stimulation of the eye. With respect to the arms, there are several further details which are interesting enough to be mentioned here.

Fig. 41—Raising the hand.

With an adult, the raising of the hand in response to sight, as when we take a book from a shelf above our head (Figure 41), is a very common movement. During the

first months a similar response to sight, moving the hand
in the direction from the feet to the head, does not occur.
The movements—like many other properties—of a human
baby have often been compared with those of full-grown
animals, for example, the apes; and, since the apes are
climbers, one might conclude that the movement of Figure
41, which is common in climbing, must be frequently
observed in babies.   We see here, that, as a matter of fact,
one has to be very critical in such comparisons.   The apes
are indeed climbing animals and, as such, are compelled
to execute the arm movement in question quite frequently;
but only in adult life,—the baby apes do not climb any
more than human babies, but cling to their mothers who
carry them about.   The comparison is therefore not
really between babies and apes, but only between human
babies and monkey babies.   When the very young baby
stretches out his arms, in response to a *visual* impression,
it is always either at right angles to the longitudinal
axis of the body or more downwards, toward the feet,
never more upwards, toward the head.   The same is
probably true for the monkey baby.

How, then, does the baby learn to raise his hands in
response to a visual stimulation?   In order to answer
this question, we must inquire whether there is during
the first few months any reflex raising of the hands, and
whether there is any possibility of this reflex being varied so
that a visual stimulation takes the place of the stimulation
of this reflex.   There is a reflex of throwing up the arms,
namely, in response to the application of cold to the skin
of the body.   During the first days the new-born baby is—
however strange this may seem—rather insensitive to all
stimuli applied to the skin, be they heat or cold or pressure
or the prick of a needle.   But after the third week, if the
baby is suddenly uncovered and exposed to a draft of cold

air, or placed on a cold linen cloth, or immersed in cool water, he may be seen to throw up his arms violently.

How, then, can these *upward* movements of the arms become associated, so to speak, with *visual* impressions? Incidentally the hands, during the upward movement, impress themselves as visual images upon the eyes,— upon the lower parts of the retinas, since all rays are crossed at the entrance to the eye. While the nervous process of the above mentioned reflex goes on, another nervous process thus starts from the lower region of the retina. The latter may be assumed to be especially intensive because it is caused by an object in motion. Although it is not perfectly known how this is brought about, it is a perfectly familiar fact that on the peripheral parts of the retina an object in motion produces a specially effective nervous process, much more effective than those resulting from the impressions of motionless objects. It therefore draws all the other visual nervous processes into its own channel and is the only visual nervous process which we have to take into account. The reflex motor effect of this process is probably a turning of the eye upwards. A considerable part of this visual nervous process is now likely to be deflected from its course by the other nervous process, still going on, into the direction of the motor organs which served the violent throwing up of the arms. Accordingly the resistance of the path leading over higher nerve centers from the lower part of the retina to the muscles raising the arm is reduced; and when this reduction of the resistance of the path has become sufficiently great, the *hand* will be stretched *upwards* in response to a *visual* stimulus coming from an object in front of the head and more or less above the eyes—a reaction which is quite common in the half-year old child. This variation of the nervous path is simply a

further example of that kind of a "variation of response" in which the same response is called forth by a new kind of stimulus.

Of course, the establishment of an habitual upward movement of the hands in response to a visual stimulation does not necessarily interfere with the reflex of turning the eyes upwards in response to the same kind of stimulation. In order to establish the habit only a part of the nervous flux of the reflex need be deflected into the new motor outlet; and the final result may be a co-existence, a loose co-ordination of the two upward movements of the hands and the eyes. A similar loose co-ordination of eye and hand movements in a horizontal direction, to the right and left, can be observed in children as early as the third month.

ELEVENTH LECTURE

Control of the feet. The ability to walk equal to rising plus balancing. Reflex of straightening the leg. Reflex of squatting. Balancing with hand support preceding free balancing. Balancing on one leg preceded by balancing on both. Walking not a simple instinct, but a compound of reflexes united largely by experience. Balancing sideways preceding balancing fore and aft. Stretching the foot reflexly toward a thing which impresses the eye. Locomotion resulting from this reflex. Creeping. Creeping on two legs preceded by creeping on one. Influences of creeping on walking. Sitting up. Finger-sucking superceded by other habits. Free standing rarely preceded by walking. One-sidedness and general clumsiness of first walking. Encouraging a child to stand: a purely negative event. The so-called instincts of constructiveness and destructiveness: rather habits.

WHATEVER may be—practically and scientifically—the relative importance of arms and legs, hands and feet, the control of the feet, the acquisition of the ability of locomotion in the up-right position, has always attracted the chief interest of the amateur observers of child life, the parents and nurses. When the child can walk, their interest in observation almost ceases. And yet, most animals possess the ability of locomotion practically from birth, so that, in this res-

pect, the year old child merely attains the level of a new-born animal. The control of the hands when once fully attained, places the child on a level which no animal ever reaches. Nevertheless, walking attracts more attention than the control of the hands, probably because the change from the perfectly helpless condition of human infancy to an animal-like condition lessens the responsibility of the child's care-takers so much more suddenly than any of the changes which raise the child above the level of animal life.

The complete ability of locomotion in the upright position involves two distinct abilities of muscular action: the ability to *rise from a lying to a standing position* and the ability to *balance on either leg*. The ability to rise is only imperfectly developed as long as holding on an object, a chair or the like, is necessary in order to rise. This imperfect ability usually precedes by several months the child's ability to rise to his feet from the floor without the aid of any supporting object. The ability to balance on (either) one leg is naturally preceded—as a rule—by the ability to *balance on both legs*, which, on the whole, is more easily acquired.

The governing reflex of the whole group in question seems to be that of *straightening the legs* in response to pressure against the soles. A child about nine months old, or even considerably younger, may absolutely "refuse" to be held on anybody's arms in a sitting, flexible position. The reflex of straightening the legs causes a stiffening of the body. The mother then naturally places the child, no longer easily held in her arms when in this straight position, with his feet on her knees, or a table, or the floor. The child then stands, in a way, but retains this standing position only because he is kept from tumbling by his mother's arms. Soon the

child learns to use his own hands, in the control of which
he has by this time already acquired considerable skill,
in order to keep from tumbling. He grasps whatever is
in sight and reach and thus learns to keep in a standing
position. Another reflex reaction is soon added to those
of grasping the things which are seen and of straight-
ening the legs when the soles are touched: that of
changing from a standing to a *squatting* position, in
response—probably—to sensory excitations in the muscles
and joints of the legs when supporting the body. The
following periodic activity must then frequently take
place. The child changes from a standing to a squatting
position while having his mother's clothes or any other
object in his grasp. Being in the squatting position he
no longer receives the sensory excitations which caused
squatting. Consequently the excitation of the soles of the
feet regains its former relative power and straightening
of the legs occurs. At the same time the touch of the
objects in the child's hands causes a bending of the
arms, an action derived perhaps from the reflex of put-
ting things into the mouth, so that the whole action
might be described by saying: the child gets up, pulling
himself up by his hands. This may be followed again by
squatting, again by raising himself, and so on. Since the
squatting, when the body is held in the upright position
by the hands having grasped an object, readily changes
into kneeling, the periodic action may be: kneeling, stand-
ing, kneeling, standing, and so on. Further, when there
are solid objects which the hands can grasp, the body
is easily pulled up from a lying to a kneeling position, so
that there may be a change *from lying to standing*, and the
reverse, provided only that the grasping hands can come
into play.

When the child stands before an object, holding on with
both hands, it naturally happens that now and then one

of the hands loses its grasp. If this happens while his legs are perfectly straight, he is likely to tumble down toward the side of the other hand; and then he will get up again. But if it happens while the legs are in a slightly bent position, intermediate between standing and squatting, it means only that the weight of the body is thrown on one side and that the leg of this side is straightened in response to the increased pressure on the sole. Thus the body is again *balanced* and kept from tumbling. This ability to balance the body is then further improved in two ways. First, the resistance of the nervous path from the sensory points of the sole to the muscles straightening the leg is lessened, possibly by the mere maturing of the inherited reflex. Accordingly, sensory excitations of much smaller intensity, caused by much weaker pressure on the sole when the body is barely beginning to lose its balance, are capable of bringing about the motor response which restores the balance. Secondly, the nervous processes starting from the excitations of the sensory points in the muscles, tendons, and joints of both legs are, by motor condensation, caused to contribute to the motor response which restores the balance temporarily impaired. This second kind of improvement, when further developed in later years into an independent "variation of response", becomes our ability to stand on one leg and to balance our body on one leg in dancing or skating. When the child has had a certain amount of practise in retaining its upright position, both hands may lose their grasp on the supporting object without causing any tumbling. The equilibrium of the body is then at any time restored by the newly acquired motor responses as soon as it is lost. We say that the child has "learned" to *stand alone*.

Let us return to the moment described in the beginning of the last paragraph. While the child is standing before

an object, holding on with both hands, one of the hands loses its grasp and consequently the leg on the other side is straightened. The body as a whole, perhaps, is thus somewhat raised, and with it that leg which remained slightly bent. But now this leg, hanging and subject to the effect of gravity, straightens somewhat; and when the body regains its vertical position and the foot of this leg touches the ground, it straightens perfectly, owing to the reflex repeatedly mentioned. The weight of the body is thus thrown again—lightly—upon the other leg. A swinging movement of the body may thus result, from the left to the right, from the right to the left. It is clear that this movement needs only a slight modification to become a regular walking movement. Children who are just beginning to walk, do indeed, usually, walk in this pendulum-like fashion, comparable to the walking of a sailor. One finds here and there in psychological literature the assertion that the walking of a child is the result of an instinct consisting in a tendency of the legs to swing fore and back in directions opposite to each other, and that these instinctive movements can be observed in a baby a few months old when held suspended. While such opposite fore and back swinging movements of the legs may sometimes be observed, it seems doubtful if they have much significance for the acquisition of the ability to walk, since one does not walk in suspension, but on a supporting surface. In any case, it is possible to derive the alternate movements of the legs in walking from the reflex of straightening each leg in response to pressure against the sole, without assuming any specific "instinct of walking."

We described how a child may learn to stand alone, balancing himself sideways. But in order to stand really alone he must also keep from losing his balance in the forward and backward directions.

From falling forward he may be kept by the very reflex of straightening mentioned before. When the body begins to move forward, less weight is placed on the heels and more on the soles. Accordingly the foot straightens, the heel is raised above the ground and the body is kept from moving forward since the centre of gravity is now behind the point of support. On the other hand, when the body begins to move backward, more and more weight is placed on the heels, the pressure on the soles vanishes, and the muscles which keep the legs straight relax. The knees then bend forward and thus a part of the weight of the body is thrown in front of the previous center of gravity, thus restoring the balance. Just as the swinging of the body to the left and right, so these kinds of movement have great significance for walking. In the walking movements of a grown person the raising of the heel of one foot may raise with the whole body the other foot from the floor and cause it by the mere force of gravity to swing forwards.

We have been trying to explain how a child learns to balance its body in the upright position without having to hold to an object. Before this accomplishment of standing free, the child usually begins to walk along by pieces of furniture, changing the hold of his hands as he walks on. What reflex is the basis of this locomotion? It seems that, in response to a visual stimulation, not only the hand but the foot, too, stretches toward the thing which impresses the eye. On the basis of such a reflex locomotion is easily explained. Imagine a child standing before a bench, holding on with both hands, and an object, say, a pencil, lying on the end of the bench to the right. The effect of the stimulation of the eye by the pencil is a stretching of the right arm and the right leg to the right. The body then falls to the right until the right foot again

touches the ground.   The body is now somewhat displaced
to the right.   The feet are farther apart than normally
and are therefore, in consequence of special reflexes which
we need not discuss, brought together to their normal
position, but of course, without any essential change of
the body sideways.   Now the whole stretching of the
right hand and the right foot to the right may be repeated
several times, until the hand grasps the object.   This
walking along the pieces of furniture or the walls of a
room can therefore be very simply explained.

At about this time in a child's development another
kind of locomotion is likely to make its appearance,—creep
ing.   As the baby happens to lie on his stomach, his eye is
stimulated by an object and the arms are reflexly stretched
forward,—but not the arms alone, the legs too are
stretched, these backward, of course; and later a draw-
ing in of all the extremities simultaneously may
occur as an alternative response to the visual stimu-
lation.   We can not apply here simply the term reflex,
but must say that the baby possesses an instinct,
since the simultaneous stretching of the arms forward
and the legs backward, and alternately the simul-
taneous drawing in of all four extremities, are the result
of selective grouping of nervous paths.   That the
alternation of stretching, drawing in, stretching, and so on,
continues for some time can be explained by assuming
that the sensory points of the muscles, tendons, and joints
stimulated in either one position are by inheritance very
closely connected with the motor points whose activity
brings about the other position.   The result of the simul-
taneous drawing in and simultaneous stretching of the
arms and legs is not necessarily, but may be, locomotion,
provided either the front or rear extremities find a better
hold on the ground.   At first, it happens not infrequently

that this is the case with the hands rather than the feet, and the somewhat ridiculous observation is then to be made of a baby pushing himself *away* from the object exciting the eye. Once now, when the arms and legs are being drawn in, it happens that in consequence of an unusually strong nervous process one of the legs, drawn in with unusual force, gets *under* the body. When now, instinctively, the arms and legs are stretched, this leg, resting with the knee on the ground and bearing the weight of the body, can not slide over the ground, but pushes the body forward. The eyes are thus brought nearer the exciting object and, therefore, receive the same stimulation as before, only still stronger. The nervous process resulting from this stimulation now tends to take the path into the leg drawn under the body rather than into the other, because it is attracted in this direction. It is deflected by the flux resulting from the excitations of the sensory points of the knee and the muscles and tendons of the leg drawn under the body, whose corresponding motor points are, of course, in the muscles of the same leg. Thus the alternate stretching and drawing in occurs chiefly in this leg. The baby *learns* to creep on one leg.

Why does not the baby, one may ask, learn just as readily to creep, at once, on both legs? The answer to this question is not that this is impossible,—only that it is less likely. During the first year the legs move, in the hip joint, much more readily sideways, than in later life. This is due to the position of the fetus before birth, which changes but gradually after birth and enables infants even for years to put their toes into the mouth, a feat impossible in later life, as we all know. When the baby is lying on the stomach and the legs are drawn in, the legs are not likely to get under the body, but move outwards, in frog fashion. At the ninth or tenth month, however, the child

begins to roll over, and when now, in consequence of an unusually strong stimulation, the drawing in of the legs is accompanied by a rolling movement of the body toward one side, a chance is given for one of the legs to get under the body. It is most natural, therefore, that the creeping on one leg should be learned first. After some skill has been attained in this, the other leg is likely to get under the body too, and the baby then creeps on both legs.

We stated that creeping usually makes its appearance about the time when the baby has learned to pull himself up and to walk along pieces of furniture. Creeping now has a pronounced influence on the child's progress in upright locomotion, in either of two ways. (1) As soon as the child has learned to creep on both legs—or knees, if we prefer this word,—he easily gets from the lying to the upright position without depending any longer on pieces of furniture or other objects which he can grasp, for the change from creeping to squatting is easy. Without being able to stand up from the ground freely, walking is of but limited usefulness. Thus creeping contributes, though indirectly, toward perfection in upright locomotion. (2) If, however, free walking is not yet a firmly established habit, the newly acquired form of locomotion, creeping, may so seriously interfere with the acquisition of that other habit as to hold it back for several months. Children who early become skilled creepers, usually learn to walk freely two or three months later than those children who little or never creep. This is comprehensible enough. The creeping child is not so exposed as the walking child to falling and to the consequent pain stimulation with its varied and strong motor responses, interfering by deflection with the learning process. Further, creeping brings the young child more quickly to the object which stimulates the child's eyes than unskilled walking, and thus as-

sures the repetition of the creeping movement by the repetition of the stimulus from nearer by, much more than walking assures the repetition of the walking movement.

In other words, the very nature of the case makes rapid improvement of skill in creeping more likely than of skill in walking; and when one form of locomotion has once been well learned, the other kind of locomotion, not yet well learned, is excluded by the simple rule of the effect of different resistances of various nervous paths, until, at a later time, new conditions arise. Some have drawn the practical conclusion, that therefore parents must prevent their children from creeping whenever they are seen to try it, before having become skilled walkers. It seems so simple: if creeping delays walking, stop the creeping and hasten thereby the walking. This conclusion, however, implies several important assumptions. First, walking is assumed to be the only kind of locomotion needed by a human being. This is somewhat doubtful. Not that we wish to assert that grown people ought to make frequent use of creeping movements, but it is highly probable that a complete analysis of our motor activities in later life would show of the elementary activities which are exercised in creeping many applications in new combinations. If this is true, the suppression of this exercise during infancy would be a grave mistake. Secondly, one must not think that the suppression of creeping before walking must be harmless since, after walking is thoroughly established, the child may be permitted to creep and thus exercise the same activities. Who knows whether exercise, then, brings about the same results in the education of the nervous system which it might have brought about previously? As long as we know nothing about this question, it is hazardous to try to improve upon nature because we, as parents,

happen to be exaggeratedly proud of our children's early accomplishments in walking and indifferent to all other kinds of motor accomplishments. Different children differ greatly in different talents, and we know that their success in life depends largely on the proper training of the most pronounced talent of the individual. It is possible, even highly probable, that a special talent means merely a special form of interconnection of the fundamental reflexes common to all; and such special interconnection may early show itself in such phenomena as this, where creeping does or does not precede walking. We might then really interfere with the child's most favorable development if we try to arrange the fundamental reflexes in groups different from those intended by nature.

To these arguments, of course, some one might rejoin that he does not feel convinced that to prevent a child from creeping during a few months can be of such consequence, positively or negatively, to his later intellectual and moral development. Very well then, we can answer that to make a child walk freely at the age of twelve months, instead of letting him use for locomotion creeping during the thirteenth and fourteenth and free walking only from the fifteenth month, does not seem to be of much significance for his later life either. The safest course in education—in this simple case as in the most complex problems of educational theory—is probably the one which interferes least with the development designed by nature and which trusts nature rather than traditional ideals of education or, worse, parental vanity, unless we have the most certain—experimental—evidence that in this or that way nature can be improved upon.

Before leaving the discussion of creeping, let us mention two further accomplishments connected with its develop-

ment.   The creeping child has acquired a second position
of rest in addition to that of lying: he can rest at any time
in a sitting position.   It is true that children can sit, with
support in the back and at the sides, when a few weeks
old, and that they can sit on the floor without any further
support when about six months old.   But the ability to
sit does not include the ability to seat himself, to sit
up.   The latter comes with creeping.   The creep-
ing child can sit up on the plain floor on which no objects
offer themselves to his hands to be taken hold of.
Thus when tired, he can take for resting the sitting as well
as the lying   position, and he often takes the former
owing to the multitude of sensory-motor reactions of
the nervous system which are only in this position possible.
For example, the child when sitting can freely turn his
head.

The creeping child further acquires a play of his hands
formerly impossible.   During the first half year, whenever
the child takes anything in his hands, he almost invariably
puts it into his mouth, and often, when he has nothing
in his hands, he puts one or more fingers in his mouth.
These reactions become less frequent when the child begins
to creep and sit up.   Objects can now call forth numer-
ous *other* responses.   The child learns to push or throw
away things, to creep after them and take them again;
and this more complicated game, more likely to bring about
repetition of activity by the repetition of stimulation
of the eye and, consequently, more likely to become a
strong habit, gradually supersedes the simple reflex of put-
ting things into the mouth.   It is the exceptional child
that retains the finger sucking habit after the acquisition
of locomotion.

We stated above that children learn to stand freely,
that is, to balance the body continuously in the upright

position, before they learn to move in this position.   While
this is generally true, there are also exceptional cases
where children, being held in the upright position, are
suddenly attracted by an object, perhaps the mother's
voice, and start off running successfully five or six steps
until they have reached the object.   In such a case
a child really learns to walk before he has learned to stand
without support.   However, as a rule, a child learns first
to stand; and then, standing, in response to a stimulation
of his eyes by an object, he moves one leg slightly toward
the object, shifts his weight so that it rests on this leg and
draws the other leg after, secures his balance, then moves
again the first leg toward the object, and so on.   One
might call this form of locomotion walking on one leg only.
In a week or two this one-sidedness gives place to the regu-
lar form of walking in which both legs take part equally.
For many months thereafter, however, a child's walk
remains clumsy because the legs are kept so far apart,
owing to the anatomical fact already mentioned that
this opening of the legs sideways is the normal position
until birth, which but gradually changes into that of the
older child and adult, and also to the fact that balanc-
ing is easier in this position.

If walking is thus the outgrowth of standing, it is well
to "encourage" free standing as much as possible after
the baby has learned to stand while holding to things.
What does it mean to "encourage" him?   Let us reduce
the process to its essential elements.   (1) The child, when
beginning to tumble, reflexly draws in his legs.   (2)   He
has often tumbled, when standing and losing the hold of
his hands.   (3) Subsequently, by a "variation of response"
he draws in his legs at once (in other words, he sits down)
when standing and losing the hold of his hands.   But he can-
not practice balancing his body if he sits down.   Therefore

(4) we give his hands the same or similar sensory impressions as if they were supporting the body. For example, we let the standing child grasp for support a small stick or pencil which we are holding, and then, gradually, we cease to hold it. The child then balances and, although nothing supports him, receives almost the same stimuli in his hands and eyes as if he were still supported by the stick in his hands. The process of balancing suffers no sudden interference by a new stimulation (caused by the withdrawal of an object from his hands) and its reaction of sitting down. The "encouragement" which we give the child is therefore a purely negative event in the education of his nervous system: we keep an obstacle out of the way.

After the establishment of free locomotion, further activities make their appearance, which are often referred to as the constructive and destructive instincts. It seems very doubtful, however, whether it is justifiable to speak of such instincts. A child, let us say, picks up one of a number of wooden blocks lying about in his room. He receives the visual stimulation of a similar block, and since the nervous path is still favored by the reduction of the resistance due to the previous stimulation, reacts in the same way, walks towards it and puts on it his hand in which he still has the first block. Since now, he cannot pick up the second block, he opens and raises his hand and, there, has before him a structure, one block upon another. Since this *double* block is a more striking stimulus than any of the single ones, it is quite natural that he returns to it, after having picked up one more of the blocks lying about. Is not all the so-called constructive activity simply a more or less complicated habit of the same kind as this very simple example? This habit of gathering and piling up must develop from the reflexes and habits which we have studied thus far, provided the child is surrounded by things

which are sufficiently similar so that two or more of them together make a similar, but more intensive sensory impression than a single one; and what child does not live under such surroundings? It is hardly necessary, then, to assume a mysterious particular instinct of constructiveness. That the habit of taking to pieces, which is to be derived from the ordinary reflex of grasping, becomes united with this habit of putting together is plain enough, for taking apart brings about ever new opportunities for putting together. Thus develop constructiveness and destructiveness as co-operating habits.

TWELFTH LECTURE

Repetition of motor activity characteristic of learning in childhood. Variation of the order of earliest accomplishments. Speech organs: whispering and singing. First speech sounds. General and specific resistances of neurons. The motor outlet of a group of successive nervous processes determined by the temporal order of the qualitatively different processes. The general resistance as well as the specific resistance reduced by any special flux; but the reduction of the specific resistance outlasting that of the general resistance. Possibility of a particular distribution of specific resistances resulting from experience.

OF the motor activities of early childhood we have briefly discussed thus far the adaptive movements of the sense organs of the head and the fundamental activities of the hands and feet. All the processes of learning which we mentioned can easily be placed in the classes distinguished by our theory of nervous activity. Most of them are simply variations of response, some are kinds of condensations. That the learning process is so quick in all these cases is largely due to the fact that the reflexes in question quite naturally lead either to an exact repetition of the stimulus or to a stimulus similar to the first and even more powerful —as when a baby piles up blocks. Even when a new stimulus caused by the first reaction is dissimilar to the

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first, it may take the path to the same motor point, either according to the law of deflection, or because of the temporarily lessened resistance in that direction, or owing to both these causes. It has become customary to refer to these *repetitions* of motor activity by the term "circular reaction." Such a special term is useful as it emphasizes the typical character of learning in early childhood in comparison with learning in later life, when the conditions are more complex and repetition of the motor activity rarely results. But let us not forget that the term "circular reaction" is not itself an explanation and would be an additional mystery unless we explain the facts themselves as we have very briefly attempted to do.

Let us emphasize that, whenever we spoke of a particular kind of movement as preceding in human growth another kind, we wished to indicate merely the most common serial order of development, and that individual deviations from this order, displacing relatively for four or five months this or that element of action, are common too. Parents should neither be alarmed nor think that they have special reasons for paternal pride if they observe that their children do this or that several months later or earlier than other people's children, or that similar differences appear among their own children. Human life during the first—and even second—year is so elementary, that any conclusions with respect to the enormously complex life of the future have as much value as the oracles of antiquity.

The new-born baby is so helpless a creature that, if experience did not teach the contrary, one could hardly believe that such a being could survive the accidents with which he must be daily confronted. When he has reached the age of fifteen months, it seems much less improbable that he will succeed in the struggle with the world. He

has learned to use his sense organs, he has acquired the ability of locomotion which he daily improves by adding further skill in walking, running, and climbing, and he has learned to use his hands so that only further exercise is wanted to enable him to shape the world in accordance with his needs.   Yet, at this age it is still easy to recognize that all the diversified human power is merely a complex of a small number of natural laws because we can still trace the child's power back to its sources.   Of course, the few muscular activities which we have mentioned as characteristic of the behavior of the infant, are not really so simple as we have—intentionally—represented them, but are movements executed each by a large group of muscles and permit each many modifications, according as the one or the other muscle in the group receives the stronger nervous impulse.   During the second year the complications grow almost into the infinite, especially during the second half of this year, when the child learns to use more and more effectively its *speech organs*.   Nevertheless, we shall convince ourseves that even now nothing happens but what can be derived from the laws of nervous activity previously stated and a few additional laws which we shall state below.

It may be well here to make a brief statement as to what the essential factors of speech production are.   There are two main classes of sound producing organs.   The first class contains only the pair of vocal chords in the throat, at the end of the wind pipe.   The vocal chords are comparable to an ordinary musical wind instrument. They produce, when the mouth organs leave the out-streaming air unobstructed, pure musical tones.   Without the vocal chords one cannot sing.   With the vocal chords in a normal condition, one could sing even though the mouth organs were completely lacking.   The vocal

chords might therefore be called the *singing organ*. On the other hand, the totality of the mouth organs, including even the nasal cavities, might be called the *whispering organ*. We can make ourselves understood even though we may be unable to sing; for example, when we are hoarse, we can still whisper. Our ordinary speech is a compound of whispering and singing, only that the latter, the "song" of speech, is not, in a musical sense, melodious.

The first cry of the baby, immediately after birth, is a song, in the sense 'n which we have just used this word. It is only two or three months later that the growth of the nervous system has progressed far enough to make possible the reflex production of speech sounds. Naturally, first those speech sounds are called forth, which require the smallest amount of sensori-motor activity, of muscular contraction. These are the guttural sounds, produced by the mouth organs located farthest back, near the throat, and the dental sounds, in the production of which the teeth (or gums) co-operate with the tongue. Neither guttural nor dental sounds require the lips. It is natural again, that of the various guttural and dental sounds those are produced first which require the smallest amount of muscular work. We are therefore most likely to hear first such sounds as *ga* or *goo* and *da* or *doo*, later the sounds of *k*, *t*, etc. The accompanying vowel depends, in accordance with the laws of acoustics, on the measurements of the cavity which the mouth happens to form at the moment. Labial sounds occur several months later, since the tension of the lips requires more muscular work: we then begin to hear *b* and *m* and nasal *n*. The popular notion that the first words pronounced by a baby are papa and mama, is an illusion.

One of our tasks in connection with speech is to explain how stimulation of the ear by different words, for example,

by the syllables *ga* and *da*, can call forth definite and different motor responses not on'y of the speech organs, but of any motor organs of the body.   Here we are confronted by a difficulty which hitherto, in order to avoid complication of the discussion, we have intentionally evaded, but which we must now face.   The question, Why does excitation occur at a definite motor point? we have always answered thus: Because over the path from the definite sensory point excited to this motor point the nervous flux finds less resistance than on any other path.   Now, it is plain that stimulation of the ear by the syllables *ga* or *da* can not mean the stimulation of two different sensory points.   It is true that the theories concerning the physiological processes in the ear show wide differences of opinion; but that the difference of *da* and *ga* is simply a local difference of sensory points from which the two nervous processes start, no physiological theory is likely to assert.   That a nervous flux takes the path toward one motor point rather than toward another, must depend, not exclusively on the sensory point whence it comes, but sometimes also on *qualitative* differences of the flux itself.   The importance of the role played by qualitative differences of nervous processes becomes still more apparent when we consider the fact that *words* differ, not only in the quality of the various stimuli, but especially in the *temporal order* in which the sounds follow each other.   For example, the main difference between the words cat and tack consists in the difference of the temporal order of a small number of sound qualities. There is no doubt that such non-spatial differences of stimulation are sufficient to bring about spatial differences in the motor response.

In order to explain these facts, it is not enough to speak of *the* resistance of a neuron.   We must speak of a *general*

resistance and *specific resistances* to particular kinds of flux. How is it possible for a single conductor to have several specific resistances? We can understand this if we assume, as we have previously done, that a nervous flux is a wandering of ions. In a highly complex chemical substance like that which makes up nervous tissue, many kinds (hundreds or even thousands) of molecules may serve as ions. Our purely mechanical analogies, of course, become insufficient at this point, for, as soon as we assume different kinds of ions, we would have to use as analogy a stream of which not always the whole substance, but sometimes only these, sometimes only those of the particles composing the substance may be in motion, while other particles uniformly distributed through the whole substance may remain at rest. This is something like the streaming in filtering and in osmosis, but even more complicated than such processes.

The assumption of specific resistances of any neuron is a brief expression of the fact that the motor outlet of a nervous process may be determined by the quality of the flux. Now we must find a way of expressing by a picture the fact that the motor outlet of a definite group of processes quickly succeeding each other may be determined by the particular temporal order of the qualitatively different processes, in order to make plain that, for example, the response to the word cat may and does differ from the response to the word tack. Let us use for this purpose the diagram of figure 42. In this figure S^0 represents a peripheral sensory point; S^1 a central sensory point from which several neurons pass on in different central directions; M^2_{abc} and M^2_{def} central motor points from each of which numerous neurons pass on in different peripheral directions. Imagine that the words cat and tack consist of two sounds, let us say, ca and ta, and that the difference

of the two words lies in the order of succession of these two sounds.   While this is only very approximately true, the simplification thus brought about is justified by our purpose.   Suppose that the nervous process belonging to the sound ca is x, that the nervous process belonging to the sound ta is y, and that in Figure 42 the neurons $S^1S^2_{abc}$, $S^2_{abc}M^2_{abc}$, $M^2_{def}M^1_f$, and $M^1_fM_f$ have an extraordinarily low specific resistance for the flux x (as indicated
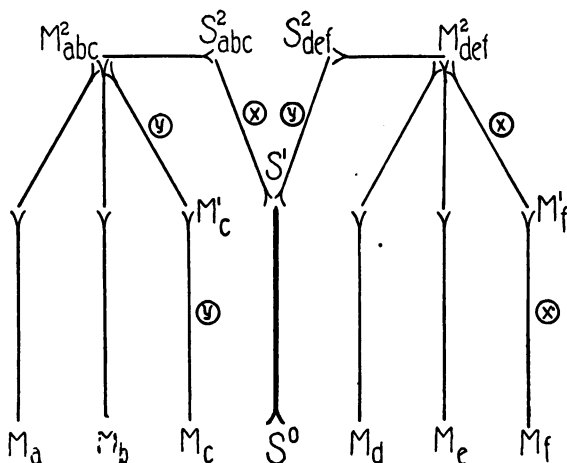
Fig. 42—Motor response dependent on temporal order of stimulation.

in the figure by the letter x inclosed in a circle) and the neurons $S^1S^2_{def}$, $S^2_{def}M^2_{def}$, $M^2_{abc}M^1_c$, and $M^1_cM_c$ an extraordinarily low resistance for the flux y (as indicated by the letter y inclosed in a circle).   Our task is to explain why the motor response occurs at M_c when from S^0 the flux x precedes the flux y, and at the different point M_f when the temporal order of x and y is reversed,—to show that this difference of response is possible.   We shall show it in exact mathematical terms.

Suppose the *fluid quantity* passing through one neuron in a unit of time to be equal to G in case general resistance is effective, equal to S in case specific resistance is effective; and that in the latter case the flux is greater, so that S is larger than G, perhaps a multiple of G.   Suppose further that the resistance between two "levels" of the nervous system distant the length of one neuron is equal to the reciprocal value of the fluid quantity passing in a unit of time.   Then, for the flux x, the resistance between S^1 and M_{abc}^2 is $\frac{2}{S}$ since the fluid quantity for each of the two neurons $S^1 S_{abc}^2$ and $S_{abc}^2 M_{abc}^2$ is S and the resistance of each neuron accordingly $\frac{1}{S}$.   The fluid quantity passing parallel through the neurons which lead from M_{abc}^2 to the periphery is, for the flux x, G multiplied by the *number* of branches from M_{abc}^2, which we shall call N.   The resistance between M_{abc}^2 and the periphery is then $\frac{1}{NG}$ multiplied by 2, since each branch has the length of two neurons.   The total *resistance*, for the flux x, between S^1 and the motor periphery represented by the total group of motor points M_a, M_b, etc. (let us call it L, being on the *left* side of the diagram) is therefore

$$L = \frac{2}{S} + \frac{2}{NG} = \frac{2(NG + S)}{NGS}$$

For comparison, we must now determine the *resistance*, for the flux x, between S^1 and the motor periphery represented by the total group of motor points M_d, M_e, etc. (let us call it R, being on the *right* side of the diagram). The resistance between S^1 and M_{def}^2 is $\frac{2}{G}$.   The resistance between M_{def}^2 and the motor periphery is to be found as follows.   The fluid quantity passing parallel through the neurons which lead from M_{def}^2 to the level one neuron nearer the periphery, is S plus $(N-1)G$, since one of the neurons branching off from M_{def}^2 has for x a specific resistance, $\frac{1}{S}$, and the $(N-1)$ other neurons have the general

resistance $\frac{1}{G}$. The resistance between M^2_{def} and the periphery is then the reciprocal value $\frac{1}{S+(N-1)G}$, to be multiplied by 2 since each branch has the length of two neurons from M^2_{def} to the periphery. Consequently:

$$R = \frac{2}{G} + \frac{2}{S+(N-1)G} = \frac{2(S+NG-G+G)}{G(S+NG-G)} = \frac{2(S+NG)}{G(S+NG-G)}$$

In order to compare the magnitude of L with that of R, let us form the ratio:

$$\frac{L}{R} = \frac{2(NG+S)\times G(S+NG-G)}{NGS \times 2(S+NG)} = \frac{S+NG-G}{NS}$$

Let us consider this formula in a few special cases. It appears that, when there is only a single motor branch at M^2_{abc} as well as at M^2_{def}, that is, when N equals 1, L attains its maximum value, is equal to R, for

$$\frac{L}{R} = \frac{S+G-G}{S} = 1$$

With increasing N, the ratio $\frac{L}{R}$ grows smaller, for each unit added to N is multiplied in the numerator only by G, but in the denominator by the larger value S. If N becomes a very large number, the ratio

$$\frac{L}{R} = \frac{S+NG-G}{NS}$$

approaches more and more $\frac{G}{S}$, which is the lower limit of this resistance ratio, for in the numerator the constant value $(S-G)$ becomes then infinitesimal relative to NG, so that the ratio reduces to

$$limit \ \ \frac{L}{R} = \frac{NG}{NS} = \frac{G}{S} < 1$$

We see, thus, that the *advantage* of the left side of the conductive system of Figure 42, which is equivalent to *smallness of the resistance ratio* $\frac{L}{R}$, for the flux x, depends on two conditions, (1) on the degree by which the specific resistance $\frac{1}{S}$ is reduced below the general resistance $\frac{1}{G}$, or, in other words, by which the flux intensity S surpasses

the flux intensity G, (2) on the number N of the specific motor points belonging to the system. Now immediately after the termination of the flux x, the flux y takes its origin from the same point S^0. In order to give x, 'n this theoretical discussion, no unfair advantage over y, we have supposed our conductive system of Figure 42 to offer to y all those resistances in the direction of "left-right" which it offers to x in the direction of "right-left." Accordingly, as the flux x found the lesser resistance from S^0 toward the left, so y would find the lesser resistance from S^0 toward the right, if nothing had preceded. Actually the flux x has preceded the flux y immediately, and this fact, obviously, must be the cause which prevents the flux y from taking mainly the path toward the right of the diagram. To this causal relation we have to give expression in an assumption in the form of a general statement. We assume that any special kind of flux, say x, reduces not only the specific resistance, for x, of the neurons in which it occurs, but *also the general resistance* of these neurons; but we assume, in addition, that the *reduction of the general resistance disappears* under lack of function *much more quickly* than the reduction of the specific resistance.

Let us see what necessitates the latter half of this hypothesis: clearly, the admittance that any specific resistance of any neuron can be the result of function as well as of mere inheritance. If the reduction by function of the general resistance did not disappear more rapidly than the reduction of the specific resistance, no neuron could be said to have any specific resistance distinct from its general resistance, save directly by inheritance. On the other hand, our assumption implies that during a short time directly after the termination of a particular flux, the general resistance may be regarded as being as

much reduced as the specific resistance. It is plain that this is of the utmost importance for any *immediate* succession of two or more qualitatively different nerve processes.

Let us make the application. The flux x from the point S^0, taking its path largely over the left side of the system of Figure 42, is immediately succeeded by the flux y, likewise from the point S^0. If y had not been preceded by x, it would have found toward the right, over S^2_{def}, a resistance less, in proportion to the ratio $\frac{S+NG-G}{NS}$, than toward the left, over S^2_{abc}. But the general resistance of the left side having ust been reduced, in consequence of the flux x, there may be for y no more resistance to the left than to the right. Suppose, then, for simplicity's sake, that the flux y divides *equally* at the point S^1, where the first branching occurs. The part passing to the right divides again at M^2_{def}. It divides about equally into N parts, since none of the neurons leading from M^2_{def} to the N motor points has a specific resistance for the flux y. The part passing from S^1 to the left, divides at M^2_{abc} also into N parts,—but into unequal parts, since the neurons $M^2_{abc}M^1_c$ and $M^1_cM_c$ have a specific resistance for the flux y, all the others only the general resistance. If N is a rather high number, that is, if the peripheral branches are very numerous, the ratio of the flux reaching M_c to the flux reaching any other single motor point on either side of the diagram, must be approximately as S to G. (The ratio $\frac{S}{G}$ is the limit.)

Summarizing now the total motor influence of x and y together, we reach the following conclusion. Of x but little flows into the motor points to the right. The main flow reaches the motor points on the left side, including M_c, but distributes itself equally over all these. Of y

a much larger (proportional to $\frac{S}{G}$) part flows into M_c than into any other motor point of the system. Therefore, the main motor response to the total stimulation x and y in this immediate succession occurs at M_c. If the succession had been y and x, the main motor response, owing to the symmetrical relations of all the conditions concerned, would have occurred at M_f. We have thus demonstrated that the mere *temporal* relation of two stimuli (x and y) *may* result in a *spatial* determination (at M_c) of the motor response.

We wanted to explain the fact that a human being reacts to the word cat in one way, to the word tack in another way. In the diagram of Figure 42, which we have used for the explanation, we have supposed certain conductors to possess a specific resistance for one kind of flux, others a specific resistance for another kind. But that nature should by inheritance completely provide for such details of stimulation by such details of resistance distribution as those of this figure, is highly improbable. Our explanation is satisfactory only if we can show that a resistance distribution like that of Figure 42 may result from "experience" during the individual's life.

In the middle of Figure 43 we find a reflex arch whose central points are named S_c^1 and M_c^1. This is one representative of the whole class of reflex arches connecting the sensory points in the muscles and tendons of the speech organs with the motor points in the muscles of these same organs. These reflexes are undoubtedly of more importance for the talking instinct of the young of the human species than any other class of reflexes affecting the speech organs. In our figure, the sensory point of the reflex arch has been marked by the word kinesthetic. This name is, of course, really too broad in its meaning, since it includes all sensory points found within any of the
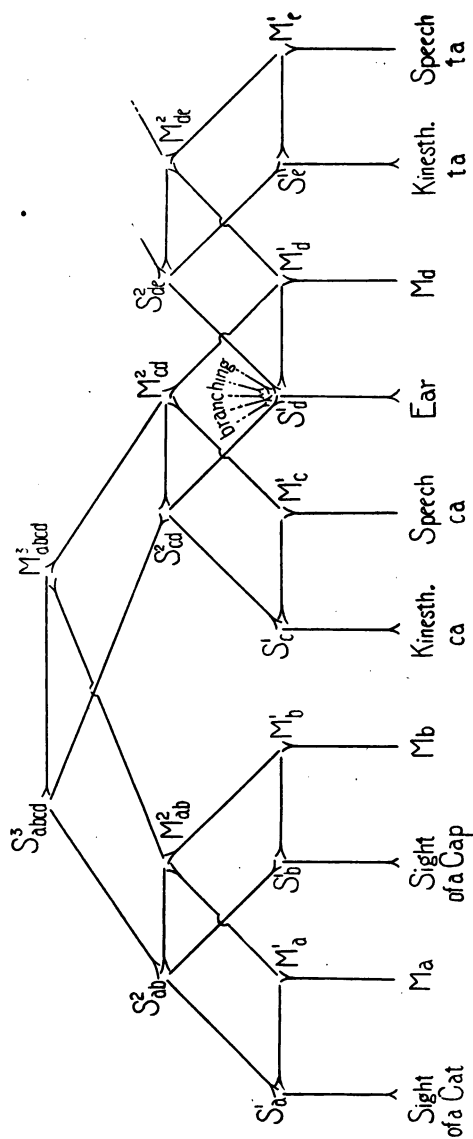
Fig. 43—An acquired distribution of specific resistance.

motor organs.   More correct, but rather long, would be
the name "kinesthetic of the speech organs."   The motor
point of the same reflex arch has been marked by the word
speech.   Below it we find in the figure the syllable ca,
which is to indicate that the kinesthetic sensory stimulation
and the motor activity are both those of the speech
organs pronouncing the syllable ca.   One of the results
of this motor activity is the production of the sound ca,
the stimulation of the ear by this sound.   The nervous
process thus starting from the ear is deflected by the
kinesthetic nervous process and takes its path from S_d^1
over S_{cd}^2, M_{cd}^2, and M_c^1 into the speech organs.   Thus
the child may be supposed to learn to pronounce the word
ca in response to the sound, to "imitate" the word habit-
ually.   But he learns to imitate also other words, for
example ta.   In this case the nervous process takes its
path from the point S_d^1 in a different direction, say, over
S_{de}^2, M_{de}^2, and M_e^1 into the motor point marked in the
figure by "speech" and "ta."

It is plain that the child, living in a human environment,
is stimulated by the sound ca most frequently when such
things as a "cat" or a "cap" or others whose names
begin with the same sound, are present and stimulate the
eye with unusual force, more strongly than the other
things which happen to be there too.   Consequently,
the strong nervous process coming from the eye deflects
the weaker one coming from the ear, makes it take its
path from S_{cd}^2 up to S_{abcd}^3 over M_{abcd}^3 down to M_{ab}^2, and
thence to the motor periphery.   Thus a specific resistance
must be established for the flux corresponding to the sound
ca, in the neurons leading from S_d^1 to M_{ab}^2; but practically
no specific resistance for any flux corresponding to any
of the sounds following ca in ca*t*, ca*p*, etc., since the
sound ca, common to all these words, occurs with so much

greater frequency. Thus the point S_d^1 becomes, so to speak, a branching point of specific resistances, for ca to the left in the figure, for ta by a similar process to the right, and for many other sounds in other directions which are not explicitly drawn in Figure 43. This is exactly what we pre-supposed for the point S^1 in Figure 42, without showing, at the time, how it could originate. The promise in this respect we have now made good. We still have to show, however, how in Figure 42 from the point M_{abc}^2 to a special motor point (M_c) a second kind of specific resistance can establish itself. Figure 43 answers our question. Whenever a cat is before the eye, the nervous process from the ear is drawn towards M_a (in Figure 43); and this nervous process contains regularly the specific flux corresponding to the t-sound. Accordingly, the nervous path $M_{ab}^2 M_a^1 M_a$ must have a very low specific resistance for this flux, compared with any other path branching off from M_{ab}^2. This explains the second presupposition embodied in Figure 42, for we had supposed, there, that one of the N branches from M_{abc}^2 to the periphery possessed a very low specific resistance for a second kind of flux. We were, therefore, entitled to the suppositions in Figure 42, and can rightly assert that we have demonstrated that the temporal order of qualitatively different stimuli may determine the motor point which responds.

THIRTEENTH LECTURE

A simple sensory excitation bringing about a temporally complex response. Some, but by no means all, temporally complex responses to a simple sensory excitation explainable on the basis of geometric-mechanical rivalry of motor organs. Multiform variation of response. Importance of kinesthetic sensory activity. Two stages in the development of speech. Reflex pointing and utterance of a dental sound. Left-handedness during the first months of life. Right-handed reflex pointing. Right-handedness and speech. Accented and gesticulating languages.

WE have discussed the fact of a temporally complex stimulation, a word, producing one response at a definite motor point. But the reverse is of no less importance, —the fact of an absolutely simple sensory excitation bringing about a temporally complex response, for example, since we are just discussing speech, bringing about the pronunciation of a word, or of a whole sentence. We must not imagine, however, that the pronunciation of every—even the simplest monosyllabic—word presents a problem of this sort. When a child one year old begins to pronounce such syllables as ga or da, nothing is required to bring about the proper motor activity but an equal, or about equal, division of the simple nervous process into several branches simultaneously. This is theoretically nothing new, a pure case of

sensory condensation.   The muscles active in such a case in producing the second sound, the vowel, may be innervated at the same time with those active in producing the first, the consonant.   Everyone can easily make the experiment which proves this.   Get ready with your mouth organs to say ga, but stop short before the expiratory "explosion."   Then do the same for the syllable goo.   You notice a great difference of position of the mouth organs and of tension of the various muscles, although the consonant beginning the word is identical in both cases.   The mouth organs, it appears, are ready at once to produce both sounds, consonant and vowel; and it may be altogether a matter of geometric-mechanical conditions—an organ being incapable of moving at once in two opposite directions—that actually the consonant, since it cannot occur simultaneously, precedes or follows the vowel.   Try the case of the vowel preceding the consonant.   Get ready to say og or ot.   Again the muscles, especially those of the tongue, have entirely different tensions before even the vowel o is heard; that is, the muscular tensions needed for the second sound begin at the same time as those needed for the first.   It is possible— indeed probable—that in the pronunciation of such words as god and dog there is no difference at all in the temporal order of the nervous activities involved, but a mere distribution of the relative resistances of the nervous branches serving simultaneously as conductors, to the effect that, in the one case, the muscular "g-tension" is stronger than, and thus becomes outwardly effective before, the "d-tension," in the other case the reverse,—the o-tension being of intermediate intensity in either case.

Let us admit that this is the true explanation of the pronunciation of many a word, but let us also be aware that this does not include the assertion that, whenever

any word is pronounced, its pronunciation results just in this way. Nothing can be more misleading than the tendency to believe that a certain event, in the complexities of human life, must regularly have the same cause. There is no question that the pronunciation of a long, polysyllabic word—not to mention a sentence—can not be the outcome of a purely geometric-mechanical rivalry of the several speech organs crowded together in and about the mouth and excited with different intensities. If a short word often does come about by this rivalry, it often may and does come about in the way typical for long words and sentences. What is this latter way?

Let us imagine, in the following discussion, a child so far advanced in experience that he responds to any simple speech sound impressing his ear by producing a similar sound with his own speech organs. In Figure 44, S_k denotes (k equals kinesthetic) a sensory point within the
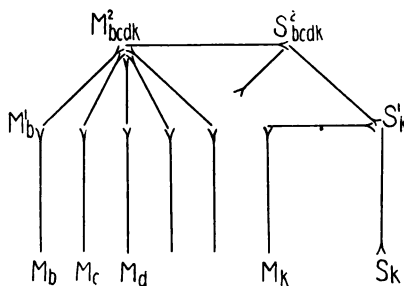
Fig. 44—Multiform variation of response.

muscular and tendinous organs of speech, or, rather, that whole group of sensory points which are stimulated by the tensions of the speech organs during the production of any definite sound, say, the word baby. The motor ending of the reflex arch $S_k M_k$ is of no direct interest to us; we might imagine that M_k represents the motor activity of saying "baby," which leads again to stimulation of

S_k, but we must note that in the following figure another point, M_a will be supposed to take this function. We know that from S_k over a higher center, $S^2_{bcdk}\ M^2_{bcdk}$, a route of low resistance may be established in the direction of numerous motor points, M_b, M_c, M_d, etc.,—each of which represents here rather a group of motor points active in the production of one definite speech sound than a single point. To take a concrete example,—a child happens to say "baby" and the mother's answering "cry," "hungry," "tired," etc., causes the child to pronounce one of these same words *in succession* to "baby." While the word baby is—probably repeatedly—produced, the kinesthetic nerve process starts from S_k. At the same time the auditory process (not represented in the figure) resulting from the mother's answer leads to the imitative motor activity at either M_b, or M_c, etc. Of these two processes, the former is attracted and deflected by the latter, and the child, instead of saying once more "baby," says now "cry," another time "hungry," etc., whatever the mother has said. The deflection of the nervous process originating at S_k, from S^1_k upwards (in Figure 44), leads then to a *multiform variation of response*. The actual response at any future time, on the basis of this variation of the nervous path, to a stimulation of S_k occurs either at M_b, or at M_c, or at M_d, etc., according as adventitious circumstances happen to favor the one or the other of these points. That the variation must be multiform, is plain enough, for many kinds of word successions having the same first word must needs occur in the experience of a child surrounded by older people. What, then, may be such an adventitious circumstance as just mentioned, making the selection among the motor outlets of the multiform nervous path? Here we approach the real problem set before us at the end of the previous paragraph.

Figure 45 is an elaboration of the directly preceding figure. S° is a sensory point at which, we suppose, an absolutely simple nervous process originates, for example, the sound of a baby crying at a distance. At S^1 a branching of the nervous conductor brings about a division of the process to the left and right. We suppose that the resistance to the left is less, so that the main flux occurs in this direction, much less to the right, as indicated in the figure by the conductors to the left being drawn in
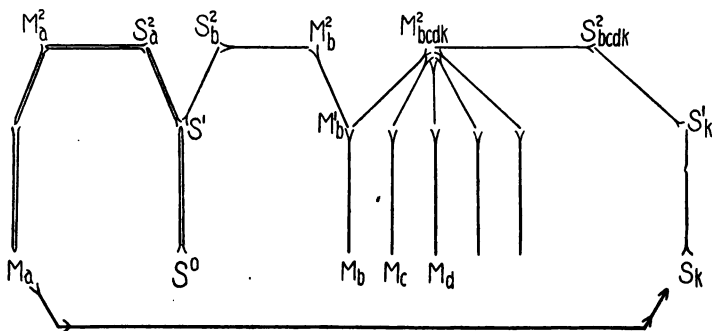
Fig. 45—A simple stimulus calling forth a temporally complex response.

double lines. The motor response occurs practically only at M_a, notwithstanding a certain amount of muscular tension elsewhere, especially at M_b. Now, imagine both these points, M_a and M_b, to represent two groups, partly overlapping, of muscular organs of speech. The sound actually pronounced is then the one corresponding to M_a; the other, corresponding to M_b, is excluded by geometric-mechanical rivalry, the same organ being incapable of moving in two opposite directions and following, by necessity, the stronger pull,—a very ordinary event in animal life. The pronunciation, through its muscular tensions, stimulates a whole group of the kinesthetic sensory points in the organs of speech; and

the group of sensory points thus affected is exactly, let us say, the one which we have formerly called S_k. Then a second word must be pronounced in response to the stimulation of S_k; and of the many responses possible, at M_b, or at M_c, or at M_d, etc., the one must actually occur which is favored by the *adventitious circumstance* that directly before this moment a nervous flux, although weak, has passed from S^1 over S_b^2 and M_b^2 through the neuron $M_b^1 M_b$. That is, under the conditions embodied in Figure 45, a *simple stimulation* of S° must result in a temporally complex response, a *succession of two muscular activities*, first at M_a and then at M_b.

Still the question is left if in our demonstration just completed we had a right to pre-suppose such a branching of the nervous conductors as represented by Figure 45 at the point S^1, which means that saying "cry" (M_b) is a rival, but weaker, response to a certain stimulation at S° (e. g., a sound coming from a distance) that is actually responded to by saying "baby" (M_a). We had a right to pre-suppose this for the following reason. The child in question is sufficiently advanced in experience to respond to a simple speech sound heard by pronouncing it imitatively,—this we have assumed. We only have to ask, therefore, whether he has the opportunity of hearing grown people say both "baby" and "cry" frequently while a crying baby impresses the sensory point S°. Of course, this must be the case, and surely, too, the word "baby" is under these conditions more frequently used than the word "cry," so that of the two paths establishing themselves from S^1 upward the one leading to M_a must have its resistance reduced much more than the one leading to M_b.

We have shown, thus, how experience can train the nervous system in such a way that one simple stimulation

is responded to by a succession of motor activities, by a temporally complex action. We do not assert that every training of this kind must conform with figure 45. There may be hundreds or thousands of other possibilities of bringing about a similar result. To have demonstrated one such possibility, as an example, is sufficient for our present purpose. Let us use this opportunity, however, to point out a fact of much general importance for all training of temporally complex reactions, namely, the necessity of *kinesthetic* sensory activity. If it were not for temporally complex reactions, kinesthetic sensory points would be rather superfluous. Why should any animal respond by particular reactions to tension in its muscles and tendons? The biological purposes of activity are, mainly, protection and nutrition. Neither is, as a rule, served directly by an animal's reacting upon internal tension. But a definite temporal order in a very complex reaction could hardly be acquired, as Figure 45 shows, without the mediation of kinesthetic sensory points, enabling the first motor activity to determine—in co-opera-tion with further conditions—the second, the second to determine the third, and so on. The greater the com-plexity of an animal's anatomy, the greater is the need of temporal order in its compound motor activities. Thus, indirectly, the kinesthetic sensory points come to serve the purposes of nutrition and preservation, to be ultimately as indispensable as the sensory points on the surface of the body. But a direct reference to any purpose can hardly ever be found in the kinesthetic sensory activity, except where—as it happens especially in the highest animal, in man—the performance of a skillful motion becomes itself a purpose, severed from all "practical" significance, for example, in athletic sports.

On the basis of our views concerning the nervous conditions of speech functions, we may adopt a distinction

which is often made by those interested in the growth of speech.   We may distinguish two stages in the development of speech, the early prattle of a child, consisting mainly of monosyllabic words, and the more highly developed—often, but only with partial justice, called exclusively the "imitative"—formation of longer words and sentences. The early prattle of a child depends on a *branching of the nervous process* so that numerous motor points receive the excitation simultaneously or almost simultaneously.   The branching of the nervous conductor is then similar to that in the special process of learning which we have called sensory condensation.   But this branching may be completely inherited.   The speech organs usually produce both a consonant and a vowel, but one precedes the other owing to geometric-mechanical rivalry.   Even sounds consisting of two consonants and a vowel may be produced in this way, like gook.   And polysyllabic words too: very easily reduplications like dadadada, or words like goocka, booppa, hoppa.   Such words are characteristic of the second year of life.   It is a mistake to think, however, that the term imitative is in no way applicable to this stage.   In this—in the main monosyllabic—prattle, as in his later talking, the child is influenced by what he hears grown people pronounce.

The second stage, from the end of the second year continuing really all through life, is governed by *kinesthetic sensory functions*, as illustrated in Figure 45; and if, as often in the nervous disease of aphasia, the kinesthetic functions are interfered with, the grown person retires to the prattling stage.   Let no one think, however, that the simpler function, governed by geometric-mechanical rivalry of the speech organs, has ceased to exist in the second stage.   Many kinds of lapses of speech in grown people and in children prove the contrary.   When a child

says *tome* instead of *come* or *dood* instead of *good*, it is not necessarily, as one might be inclined to believe, because he can not pronounce gutturals,—they are the class of consonants most easily produced. Most probably, in such a case, the nervous function described in Figure 45 is not perfected, and simultaneous innervation, by means of a mere branching of the nervous conductor, governs the pronunciation. Then we understand why *tome* should be pronounced instead of *come*, for the branching of the nervous conductor is more ready to serve *t* and *m* together, both of which are produced by the speech organs located in the front of the mouth and co-operating naturally in many ways, than to serve *k* and *m* together, of which the former is produced by speech organs located in the back part of the mouth and therefore less naturally co-operating with the other. That any imaginary difficulty of producing guttural sounds need not have anything to do with the case, is demonstrated by the example of a German-speaking child who insisted upon saying *kragen* instead of *tragen*,—certainly not because gutturals are more easily pronounced than dentals, but because the other significant consonants of the word, the German *r* and the *g*, are both gutturals, with a common nervous conducting apparatus.

In our ninth lecture we mentioned the reflex of pointing with the index finger at a thing which impresses the eye. We said that this reflex appears at about the same time when the first articulated sounds (usually guttural and dental—ga and da) are instinctively produced by the baby. But the act of pointing is not accompanied by a guttural, but by a dental sound—the baby pointing and saying dadada. We recall, too, the interesting fact that in all Germanic languages the demonstrative pronouns begin with a dental sound. Why does the baby say da

when pointing at anything, and not ga? The answer is to be found in the same considerations which we have just applied. The act of pointing sets in motion one of the extremities of the body. The nervous process, one of whose divisions goes into this extremity, can naturally reach by one of its other divisions more easily the muscles of the frontal part of the mouth, belonging to the periphery of the body, than the muscles of the throat, belonging to a different, an internal, system of muscular activity. Try yourself to accompany a pointing movement by a dental or a guttural sound. The latter seems less natural.

When the reflex of pointing first occurs, we notice that the pointing is done far more frequently with the right than with the left hand, whereas previous to this time the right hand is by no means favored in action. The functional connections between the reflex of pointing, the growth of speech, and the development of right-handedness, are so interesting that we must discuss them more in detail. A baby two or three months old, in using the hand, for example in order to put the fingers into the mouth, unquestionably gives preference to the left hand in about two-thirds of all cases. That is, one observes during the first few months about two activities of the left to one of the right hand. Toward the middle of the first year this preference disappears, and both hands are now used with about equal frequency. This is also the time when speech sounds, although hardly yet imitative, become more frequent. During the second year—say, at the fifteenth month, making allowance for the enormous individual differences—the right hand begins to predominate, and about the same time speech enters upon that rapid development which insures to this art its being the distinguishing feature of a human being as compared with an animal. As little as it possesses

speech in the human sense, can any animal be said to be right-handed or right-sided. In animals both sides of the body function about equally.

It is probable, although not absolutely certain, that the totality of these facts may be explained in the following way. The left hemisphere of the normal human brain, as has been known for nearly a century, has functions different from those of the right hemisphere; not merely in so far as the right hemisphere is more closely connected with the left side of the body and the left more closely with the right side of the body, but through its significance for the functioning of the speech organs. Certain nervous paths, most probably those leading from the kinesthetic sensory points of the speech organs, have their higher centers in the temporal part of the left hemisphere exclusively, and when a person suffers from aphasia, it is in this part where a lesion is regularly found in a postmortem examination. It is clear, then, that the growth of speech during the second year of life is coincident with and dependent on the inner development of this part of the brain; and since this part of the brain is also closely connected with the hands, but more closely with the right than with the left hand, it is to be expected that speech functions bring about activities of the right hand. Thus we understand why certain movements of the baby's speech organs are accompanied by pointing movements of the right hand, and why grown people, too, so frequently accompany their talk by gestures of the right hand.

As to the time of the development of the right hemisphere of the brain in comparison with the left, we are entitled to a conclusion from analogy. The human brain with its complex functions is not fully developed until years after birth. The brain of larger animals of a

longevity comparable to that of man, with its simpler, but no less important functions, is fully developed some months after birth. May not a similar rule govern the development of the left and the right hemispheres? The temporal part of the left hemisphere, with its highly complex speech functions, is not fully developed until years after birth—so much we know. By analogy we conclude that the symmetrically corresponding part of the right hemisphere, with its simpler, though no less important functions, develops to maturity at a much earlier period. If this is so, activity of that hand which is governed by the right hemisphere, must become conspicuous at a much earlier period than activity of the other hand. Indeed, the left hand, whose musc'es are closely connected with the temporal part of the right hemisphere, is the preferred member in the activities of the first few months after birth. Thus the fact that a normal human child is at first left-handed and then changes into being right-handed, to remain so during his life, appears plain enough.

Movements of the speech organs are likely to be accompanied by pointing movements or other gestures of the right hand, or of both hands because of the nervous co-ordination of the hands, so we said. Some languages, especially the English, habitually put an enormous vigor into the enunciation of one definite sound of each word or sentence. The English language, that is, is a strongly accented language. According to our law of nervous deflection we might expect that the strong nervous flux leading to the enunciation of the accented sound should interfere with the execution of the hand gesture. It seems that this explains the absence, or at least remarkable infrequency, of gesticulation in speakers using the English language. In the French language, on the other

hand, there is no accent worth mentioning, and the reflex gestures of the speaker are therefore fully preserved. Accent is thus a substitute for gesture.   This explanation seems more generally applicable than the customary one referring to racial differences of temperament as the exclusive cause of the difference in question.   Such a difference of "temperament" would remain both ethnologically and psychologically rather mysterious.

FOURTEENTH LECTURE

Spatial perception. Inherited responses to spatial form. Acquisition of unitary groups of conductors serving all objects of the same design. Mutual attraction of nervous processes of equal strength. Melody and harmony. Two kinds of tonal similarity. Neurons applying their specific resistances in various degrees to a variety of processes. Rhythm equals subjective grouping of objectively uniform excitations. Habits of performing group motions consisting of one chief and one or several preparatory movements. No counting in rhythmical perception. Why all common rhythms are of the doublet and triplet kind.

THE function of the nervous system is said, by some, to have three aspects. But to distingiush them one must narrow his view to an exclusive consideration of the sensory function, the motor function, or the collecting and redistributing function of the system, of which none can have any separate exis-tance. How artificial the separation of these functions is, appears from our previous discussions. The function of the nervous system is always one which *carries sensory excitations to motor points* over short or long, relatively simple or complex paths. A distinction of different aspects of this single function merely offers convenient headings under which to place chapters of a prolonged discussion. Thus we may say that we are now to consider a certain sensory aspect of nervous function, namely that

which is customarily referred to by psychologists under the name of the *perception of space*. The sensory points here in question are mainly those of the cutaneous surface of the body and the retinas of the eyes. The problem which concerns us is, broadly stated, this: How can we explain the fact that group stimulations of a particular geometrical design, occurring now here, now there on the sensitive surface, are capable, within limits, of calling forth identical motor responses although the sensory elements stimulated may be either entirely different or only partly identical?
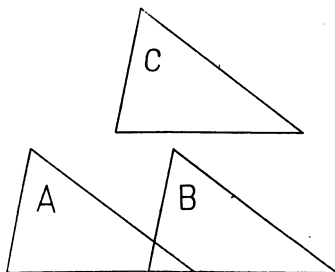
Fig. 46—The simple perception of space.

To state the problem less abstractedly, let us take an example. A triangle is before our eyes. We move, and the triangle appears on a different part of the field of vision, at *B* instead of at *A*, in Figure 46. The sensory elements stimulated in both cases are partly different, partly identical, as the figure shows immediately. We move again and the triangle appears again on a different part of the field of vision, at *C*. This time altogether different sensory elements are stimulated. In all three cases our reaction is about the same; if it is a speech reaction it consists probably in our pronouncing the word triangle. Whatever the reaction may be, on general

principles of theoretical explanation we must be able to
conceive of it, because of its definiteness and identity,
as the result of a nervous flux proceeding somewhere
within the nervous system from a definite single point.
Our problem, then, consists in showing the possibility of
all the nervous processes which come either from A, or
from B, or from C, uniting in the same single point within
the nervous system.   From this point on toward the motor
periphery the nervous process may then undergo all the
influences hitherto described in general, leading to all
kinds of variations and combinations of motor effects.
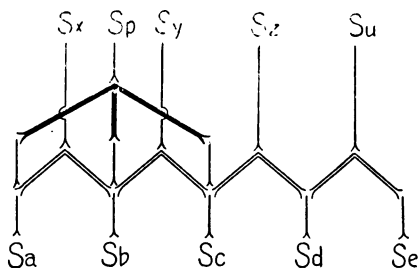
Fig. 47—Sensory points serving form stimulations.

Figure 47 contains two classes of points which are
marked with letters. The points marked S_x, S_y, S_z, S_u, S_p
are those among which the central point just mentioned
is to be found.   They are quasi-sensory points, not located
in the sensory periphery of the nervous system, yet to be
regarded, in the light of all our previous discussions of
function, as if they were truly sensory points.   In them
are collected the conductors which unite the genuine
sensory points S_a, S_b, S_c, S_d, S_e into the groups spoken
of above as essential for the so-called perception of space.
In the point S_x of the figure two true sensory points are
grouped together, S_a and S_b.   One of these, S_b, is also

grouped with S_c in the quasi-sensory point S_y. All three, S_a, S_b, S_c, are united in the quasi-sensory point S_p. From each of the points S_x, S_y, S_p a definite chain of neurons, not given in the figure, leads to a definite motor outlet. Suppose, now, that three other sensory points are united in another quasi-sensory point $S_{p'}$ (not shown in the figure), three others in $S_{p''}$, etc., and that from all these quasi-sensory points S_p, $S_{p'}$, $S_{p''}$, etc., the excitation is carried to the same motor point M_p. Thus group stimulation of a particular geometrical design, though occurring now here, now there on the sensitive surface, can by way of S_p, $S_{p'}$, $S_{p''}$, etc., lead to the same motor response at M_p. Only this question is left, whether we have the right to assume that by both inheritance and experience, neuron connections like those of Figure 47 can exist.

As to inheritance, observation of the reactions of young animals as well as infants proves that we have this right. The present writer has repeatedly observed that children a few months old, with no experience whatsoever as to danger from animals, reacted definitely and strongly with shrinking, tension of the facial muscles, and crying when shown the face of a stuffed puppet representing a little
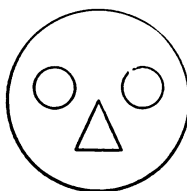

Fig. 48—Spatial stimulation with inherited response.

pig of simple features like those of Figure 48. Since the reaction was the same in the case of different children and of somewhat different puppets, the conclusion is to be drawn that it was a reaction to the common features of

these puppets, consisting in a circular head, two conspicuous circles within, the eyes, and a conspicuous triangle, the snout, as shown in the figure. Obviously, then, the sensory points of the child's eyes are by inheritance combined into a large number, perhaps thousands, of groups so that all the points stimulated by an appearance, in upright position, more or less like that of Figure 48, send their excitations. to a single motor point or a single central point whence the flux is redistributed to cause the definite reactions mentioned. There are probably also many other kinds of such groups, of other shapes, inherited by each individual of the human and animal race. In animals, too, similar definite reactions to the appearance of an object never experienced before have been reported by various observers.

The other question is whether a grouping of sensory points like that of the diagram of Figure 47 and the further grouping (above mentioned) of such points as S_p, $S_{p'}$, $S_{p''}$, mentioned above as serving the same geometrical design on the sensitive surface, can be acquired during life. For this it is merely necessary that when a definite group of the sensory points on the retina or skin is stimulated by an object, a definite motor response is strongly called forth by a certain additional property of the same object or by any other property of the total situation. If this is the case, the nervous processes, in accordance with the law of deflection, must all be drawn into a single channel, the one leading to the motor response just referred to. That is, somewhere within the nervous system, they must all be united, as processes coming from S_a, S_b, and S_c may be united in S_p. Now, the next moment, the same object may stimulate other sensory points, partly identical with or entirely different from the former. What enormously simplifies the whole problem is the fact that of all the

groups which might be stimulated by the same object, only those relatively *few* are ever likely to be stimulated which are displaced without any rotation, like the triangles in Figure 46. This new stimulation by the same object may result from either a movement of the object or a movement of the eyes or of the whole body. The objects which move are usually animals, moving over the ground without rotating around any horizontal axis within their body. Accordingly, their images on our retina do not suffer any rotation. If it is our body that moves, it does not rotate either, nor do our eyes, so that the image is again displaced on the sensitive surface without any rotation to speak of. The flux from the sensory points now stimulated is by deflection carried into the same motor point. Thus a large number of conductor groups of low resistance leading to the same motor point must be established—all these groups having in common that the sensory points *form a geometrical design of the same position with respect to the vertical;* for other positions could be brought about only by rotation around a horizontal axis, which is a relatively infrequent occurrence in nature. Such a response having once been established—or else being inherited—it can be varied like any simple response by further experience. For example, the first response of a child to the sight of a cat may be one of shrinking; later, by variation, it may be one of approaching and petting the animal.

This is simple enough. The only question which might still be asked in order to make this kind of reaction—to spatial stimulation—perfectly plain, is this: Why does the main flux, in case S_b and S_c (in Figure 47) are stimulated together with equal intensity, pass in the direction of S_y? Why does it not pass in the direction of S_b as well? Secondly, why does it not scatter almost equally in the directions of S_x, S_y, and S_z? To answer this question

we need only refer to the law that nervous processes mutually attract each other. If one of them is stronger than the other, the result is a deflection of the weaker one from its course. If they are equally strong, the result is a union whenever the conditions of the case make a union of the several processes possible. Thus the two processes coming from S_b and S_c, instead of scattering in the directions of S_x, S_y, and S_z, unite in the only neuron in which they can unite most directly, the one leading to S_y, whence the flux goes on directly or indirectly toward the motor periphery. Saying that the flux takes its path over S_y, we mean, as always, strictly only that the major part takes this path and the muscular reaction depending on S_y overpowers all other muscular reaction. If S_a is stimulated together with S_b and S_c, the three processes can not unite either in S_x or in S_y, but only in S_p. Accordingly, the muscular reaction is determined by S_p. That in consequence either of inheritance or of experience definite motor responses succeed group stimulations of a particular geometrical design, is thus made plain on the basis of our general assumptions.

Another one among the peculiarities of the so-to-speak sensory aspect of nervous function, of much interest to the psychologist because of its significance for the theory of esthetics, is the perception of *melody and harmony* in music. Certain tones, affecting the ear either in succession or in simultaneity, bring about motor reactions like those which generally, in any division of sense, are the effect of stimulations of *similar* kind—similar in a greater or lesser degree. Neglecting the fact that these reactions to music are chiefly emotional—to the question what emotional means we shall return later—we may use here the following quite possible and very concrete example. That the example is not taken from every one's daily

experience may be excused by the fact that common behavior hardly ever contains any unemotional reaction upon musical tones. Suppose somebody has been trained to perform a particular responsive act whenever he hears the same tone twice with a short time interval between. The responsive act may consist in his saying simply "same tone" or "the tones are alike." We notice that he responds in this particular way frequently even when the second tone is an octave of the first, and also, though less frequently, when the second tone is a fifth of the first. Obviously, then, the nervous flux of the octave is, not identical with, but similar to that of the first tone stimulation; and the nervous flux of the fifth is also similar, though in a lesser degree, to that of the first tone stimulation.

If the first tone had been one of, say, four hundred vibrations and the second tone one of four hundred and five, it would not appear strange that the second nervous excitation should have affected the nervous system like the first. On an earlier page we spoke of the specific resistance of neurons. It goes without saying that any neuron having a specific resistance for the flux which is caused by the auditory sensory points being jerked four hundred times in a second, has this specific resistance also for a flux caused by slightly more, or less, frequently occurring jerks. But here observation teaches us that one neuron must apply the same specific resistance to a flux caused by jerks occurring in the ear twice ("octave") or one and a half times ("fifth") as frequently, —only in various degrees with various ratios. Rejecting all speculation on this point, we are compelled to accept the bare fact that with respect to the specific resistance of a neuron a *simple ratio* of jerks can take the place of a *near number* of jerks in the auditory organ. A full know-

ledge of the chemistry of the nervous flux may in the future make the evident fact plain to our understanding.

It does not follow, however, that in every neuron without exception a simple ratio must have this effect. On the contrary, there is good reason to believe that only a minority of all the neurons connected with the ear function thus, for there are even people—those who are entirely unmusical—in whom practically no "ratio" reactions of this kind are found, who, we may assume, possess no neurons whatsoever of this vicarious function. In infancy, too, this function in auditory excitation seems to appear later than the other, so that we may regard it as a comparatively recent acquisition of the race. Now, if all the neurons do not apply their specific resistances to simple-ratio stimulation of the ear equally as to near-number stimulation, the subject's ultimate motor response, the muscular reaction proper, need not be identical in every case of similar and of simple-ratio stimulation of the auditory organ. An example will show what conditions are favorable to a response of this sort,—the nature of the just preceding reaction especially. Let a tone and its octave stimulate a person's auditory organ. Suppose that, a fraction of a minute before, many of those neurons have carried excitations which do *not* apply their specific excitations to simple-ratio stimulations of the ear:—two slightly mistuned tones may just have affected the ear. Then these neurons owing to their recent functioning, rather than the others, will function now again and the motor reaction to the two tones must be the usual one to two "tones quite different," because of their difference in the number of jerks. Our general explanation of that property of the nervous system which is the basis of all music (of melody and harmony) by no means involves us—as one might fear—in the difficulty that the motor reaction to tones of a simple

ratio of vibration rate must inevitably be always the same as the motor reaction to tones of similar vibration rate.

No attempt will be made here to answer the question as to the *origin* of the fact that a limited number of the neurons of the human nervous system *apply their specific resistance in various degrees to a variety* of auditory nervous processes provided that the frequencies of the jerks received by the ear form certain simple ratios. Too much printer's ink has already been wasted on proposed answers to this question, of which none appears thus far entirely plausible.

A third peculiarity of the sensory aspect of nervous function, which we shall discuss here, is the *rhythm* which is often observable—not in animals but in man—in the motor reactions when the stimuli occur at fairly regular intervals but without being combined into any groups by physical accentuation, objectively. We mean by rhythm the subjective grouping, the fact that a definite, unitary response corresponds, not simply to each single stimulus, but rather to a group of stimuli,—this group recurring in the sensori-motor activity with regularity for some time.

Take this example. I am sitting at the open window through which the regularly recurring puffs of a distant steam engine reach my ear. Suddenly I am imagining the strains of a waltz. The puffs of the engine seem to turn into the successive chords of the music and, at the same time, seem to have lost their former absolute regularity. They incite me to beat with my hand; but the movements of the hand are not all equal. Six of them fall into a group, and this group again consists of two parts of three beats each. The first of the six beats is executed with great vigor and mainly from the shoulder joint. The following two are executed with a much weaker movement

of the hand, and then too, the upper arm takes hardly any part in the motion, which occurs from the elbow joint rather, or even merely from the wrist. The total time occupied by these two beats is slightly less than double the time of the first beat. The fourth beat (the first of the second part) is comparable to the first of the group, but has the same properties in a slightly lesser degree. The fifth and sixth are comparable to the second and third. We call this the perception of rhythm—of a particular rhythm in this particular case. How do I come to be affected in this peculiar way by absolutely regular puffs of a steam engine?

This habit of reacting is acquired by each individual in innumerable different ways. Let us at once give a concrete example. Imagine a gardener having planted a double row of plants like the stars of Figure 49. In order to keep
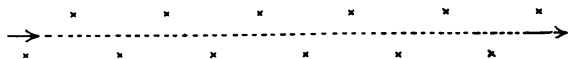
FIG. 49—How the habit of rhythm may be acquired.

the loose earth, just thrown around the roots of each plant, from drying, it is necessary to compress it and thus render effective the capillary attraction which draws the moisture from the lower soil. The quickest way of doing the work is to walk along the center line of the double row and to step, with the full weight of the body, on each of the places which need compression, using, of course, alternately the right and the left foot. Now, try to walk ahead, doing this, and observe how your legs most naturally act during this procedure. While you are standing on your right foot, the muscles of your right leg are strained in such a way as to keep the leg straight and able to support the weight of the body, but not in such a

way as to throw readily the weight of the body upon the other foot.   For this a complete readjustment of the muscles of the right leg is requisite.   To bring about the muscular readjustment, you most naturally let the body fall lightly upon the left foot and let it swing back to the right.   Thus you assume that new position on the right foot in which the tension of the various muscles is adjusted so that the full weight of the body can be thrown on the left foot forcefully and skillfully.   The left foot now hits exactly the spot in the left row on the ground where the compression of the soil is needed.

What, then have you really done instead of stepping simply from the right foot upon the left?   You have made two intermediate steps of a much less forceful kind, merely preparatory to the proper stepping on the loose soil.   Before you now step on the next spot in the right row, you make again two preparatory steps, and so you continue your agricultural work most easily (that is, most naturally) and most effectively.   Between each two compressing movements there are always two different preparatory movements, both of an easy character.   Why just *two* different preparatory movements?   Obviously because man is a symmetrically built and two-legged animal.   If man were built like a horse, the total muscular activity might, and probably would, be rather different.   Surely, if man were a three-cornered animal, the case would be entirely different,—most probably he would not even have any tendency then to plant his garden in double rows.

One must not think that all this cannot have much significance for rhythm, since most people who have rhythm have never planted any garden in the way indicated.   This is true.   The one example of human activity was only to show that the activities of man in general tend to be habitually of such a nature that the main motion is preceded

by a double or single (example below) preparatory movement of a less forceful kind. Thus the human nervous system becomes accustomed to muscular innervations arranging themselves in a group of three (or two) successive innervations of which one is strong. The individual possessor of the nervous system then has the habit of performing group activities rather than entirely uniform motions which follow each other like the puffs of an engine. He may then be said to have the habit of *rhythmical perception*, that is, the habit of reacting by a group activity to a series of perfectly uniform stimulations like our series of puffs, which directly, by their objective properties, in no way incite any group activity. That animals do not acquire any such habit of rhythm is readily understood if we only consider that horses or dogs do not habitually perform any systematic labor at all comparable to that mentioned above of a gardener. But in man's life systematic labor plays an important part—and not only labor, but also systematic play, like dancing a waltz. When the nervous system has once thoroughly acquired the habit of a particular group activity, this activity may by a "variation of response" quite readily show itself in a part of the body where it was not, and in a motion in which it was not, acquired, as when I beat with my hand the rhythm of a waltz while my feet are at rest. It may by a further variation of response result in my naming an auditory impression as when, in reply to a certain question, I speak or write: "This is a waltz," *without* having in the least had recourse to *counting* up to three, the distinguishing number of that rhythm.

Our example of the gardener illustrated the acquisition of the habit of triplet activity. We have also referred to the existence of the habit of doublet activity. If we are permitted to take our example again from agricultural

work—it is still easier to find examples in the shop or factory—we may imagine a gardener who has planted a single line of plants and has now to compress the soil at the successive spots. Suppose he does this with his left foot. He must then make before each compressing movement of the left leg one preparatory movement of the right leg (or three if he chooses, one of the right, one of the left, and one again of the right leg) in order to assume the proper position to the right of each plant. We thus have one weaker muscular innervation between each two of the main innervations, a *group* activity composed of *two* motions, one strong, one weak.

Our most common rhythmical perceptions are of the doublet and triplet kind. There are also familiar rhythms composed of four, six, eight, twelve, and sixteen units. These are simply compounds of doublets and triplets. For example, a group of twelve is a doublet of six, and this group of six again is a doublet of three; or the group of twelve may be a triplet of four, etc. We are very familiar with such groups in dancing. It is a common, but on that account no more correct, belief that people dance because of an inherited "sense of rhythm," a special instinct which impels them to perform group movements of two, three, four, six, eight, etc., elements. The truth seems to be rather that we have a sense of rhythm because we dance than the reverse, that we dance because of an instinct of rhythm. Dancing is a group activity of our muscles which is easily learned because of its relative simplicity and its adaptation to the human anatomy. Since this activity is so easily learned and performed, it is used for sport, for play. Thus it becomes one of the sources of the general habits of rhythm.

All common rhythms are reducible to doublets and trip-

lets by division with two or three.   There is nothing mysterious in the fact that groups of five, seven, or nine units are not common rhythms.   This is merely the consequence of the fact that systematic labor or play does not readily employ the human body with its two hands and two feet in such a way as to lead to the acquisition of a habit of combining, say, four different weak, preparatory motions with a strong, fifth motion into a single group. If one invents a certain playful activity of five or seven elementary motions—one of them being strong, the rest serving as different preparatory movements—and exercises it until it becomes perfectly habitual, he acquires a rhythmical perception of a quintuplet or of a septuplet which appears no less natural and quasi-inborn than the rhythmical perceptions of a triplet and doublet.   Such has been the present writer's personal experience.

Let us understand, then, that the so-called "perception" as well as the execution of rhythm, as a nervous function, is simply successive group activity, involving in each case the successive innervation of a definite number of different muscle sets.   One reason why in the text-books rhythm is so shrouded in mystery is clearly this, that it is usually thought of as an instinctive nervous reaction to number instead of being regarded as a (numerical) habitual group of successive sensori-motor activities unified by their leading to a single end.   Number enters into such a function really only as a conception of the scientist who describes it, not of him in whom the function occurs.

FIFTEENTH LECTURE

Imitation. Auditory and visual imitation at different stages of life. Kinesthetic imitation not inherited; of little importance even when acquired. Emotional reactions. Either contraction or relaxation prevailing in either organic or skeletal muscles. Emotional reactions inherited. Emotional reactions either of direct or of indirect value, for example, as signals for social interaction; especially in primitive man and in animals. Civilized man, deriving little benefit from his emotional reactions, practically unable to control them by experience.

WHILE discussing speech we had to mention the fact that certain activities of the speech organs occurring in response to auditory stimuli have the peculiarity of bringing about sounds very much like those which served as stimuli in the first place. In any such case where *the motor response repeats the stimulation* we speak of *imitation.* "Imitation," therefore, is not the name of a force, but of a mode of reaction. Here the subject has imitated the sound heard. But imitation, of course, is not restricted to auditory stimulation. In auditory stimulation it makes its first appearance as one of the great factors of human education,—during the second year of life. Visual imitation attains its maximum of importance about a year later. While auditory imitation plays a part of ever decreasing significance as life advances,

visual imitation determines our actions in all stages of life. The infant imitates the speech sounds which are produced by children and older people in his presence. The eight or ten year old child has almost ceased to imitate the speech of others. How slight the tendency to imitate speech has become in grown people, all those know from experience, to their regret, who have ever learned or taught a foreign language. Grown people will do a hundred other things rather than repeat over and over again a phrase just heard, as small children do, —the secret of children's rapid success. It is quite natural, however, that auditory imitation is so strong during the second and the following few years and so weak later. The child must learn to speak early in life, and he learns by imitation. When this is once accomplished, imitation is no longer necessary. Aside from *learning*, *auditory* imitation has no value of its own. With visual imitation the case is quite different. It is true that a good many skillful movements may be and are learned by *visual* imitation; however, the *imitative act itself*, aside from all learning, has an enormous biological value all through life, in old age no less than in middle age and infancy. When we see a crowd gather on the street, we immediately run to the spot ourselves,—not because we still have to learn how to run to a point seen, but because it is of immense value for our social life to do at any time what we see other people do, exceptions notwithstanding.

There can hardly be any doubt that auditory imitation is largely the result of inheritance. All the elementary sounds are imitated because the necessary paths of small resistance are inherited. The apes, having practically the same vocal organs, do not, in our zoological gardens, acquire human speech, obviously because this factor of nervous inheritance is lacking. One might argue that

the existence of the so-called "baby talk" demonstrates
the importance of experience in auditory imitation.   It
is true that baby talk is the result of the child's experience,
not of his inheritance.   But baby talk is not acquired by
imitation on the child's part.   The infant babbles   in
response to all kinds of stimulations, auditory or not
auditory.   The sounds thus produced are imitated by the
parents and used by them in the baby's presence with
reference to particular situations.   The child then learns,
by this experience, the meaning created by his parents
for these sounds, which are in the main reduplications;
that is, he learns to use these simple words in these particu-
lar situations,—by imitation on the part of his parents.
Thus he acquires the talk peculiar to the nursery.   It is
clear, then, that the existence of baby talk is no argument
in favor of any importance of experience in auditory
imitation.   Inheritance   brings   about   adequately   the
imitation of all *elementary* speech sounds.   To *combine*
these elements into complicated groups composed of
many   successive   elementary   sounds,   requires   indeed
both experience and reflex imitation on the child's part,
—we have studied the process in a previous lecture.   The
imitation of the elementary sounds, however, is regulated
by inherited reflexes.

In visual imitation, on the other hand, there seems to
be little dependence on special inherited reflexes.   Even
the simplest movements which are executed by visual
imitation seem to depend on experience.   We have dis-
cussed in an earlier chapter the simplest reflex movements
of the hands and feet.   There is in them no imitation of
any movement seen.   Only when the child begins to
make new movements by *experience*, can imitation be
observed.   And even in these earliest movements learned
by experience there is hardly any imitation.   The child

learns, for example, the upward movement of his hands which we make in order to take a thing from a shelf above, —but not by imitation, as we have found. He learns to creep, to stand, to walk, but not by imitation. It is only after he has acquired these skillful movements of his hands and feet, that visual imitation becomes conspicuous. Now we observe that the little child, barely able to walk, joins us when we are standing with our back against the wall and takes his place at our side, leaning his back likewise against the wall. Now he puts his hat on when we put our hat on. Now he places an open book on the music stand of the piano before he strikes the keys with his little fingers, because he has seen us open our music before striking the keys with our fingers. Visual imitation, therefore, depends altogether, or practically altogether, on experience; there is scarcely any inherited visual imitation.

We have discussed auditory imitation and visual imitation. Shall we add, as a third important class, kinesthetic imitation? If we apply the term imitation to every sensori-motor process which brings about directly a repetition of its stimulation, we might speak also of kinesthetic imitation. But whoever would restrict the term to cases where the stimulation results from an extra-corporeal (visible or audible) phenomenon, should not use this phrase, for kinesthetic stimuli are not external, but physiological phenomena. He might then, instead of adding a third class of imitation, speak of circular sensori-motor processes. In an earlier chapter we have already had occasion to mention that circular reactions are of much importance in the acquisition of skillful movements because they hasten, through repetition of the same nervous activity, the establishment of paths of low resistance. The question which interests us here is

this: Is kinesthetic imitation, if we are permitted to apply the term, largely inherited?

One might think that the inheritance of kinesthetic imitation, of the occurrence of the motor response in the very muscles in which the sensory excitation occurred, is self-evident from the nature of the case, for two reasons. Did we not state the great importance of kinesthetic excitation for habits of temporally complex, that is, of serial, reactions? Secondly, should not nervous connections of low resistance be inherited between sensory points and motor points located side by side in the body, when many such connections are inherited between widely separated sensory points and motor points? Both these are false arguments. As to the latter, it is clear enough that in the lowest organisms, having no nervous system, the motor response occurs primarily at the point itself which has received the stimulation. It does not follow, however, that after differentiation of the tissues the sensory and motor points, because they are originally identical, must be closely connected by nervous paths. It is true that in the peripheral parts of the body the sensory and motor neurons of the same region usually run parallel in big bundles, the so-called nerves. But within the central nervous system they separate; and they are connected to form short reflex arches only where the functional needs of the organism unite them, as in the case of all other sensory and motor neurons. The former argument has no greater strength. Not everything of great importance is necessarily inherited. Further, in so far as kinesthetic excitation plays a part in the execution of habitual *serial* reactions, we have no imitation, for each kinesthetic stimulation in a serial reaction brings about a contraction of a new set of muscles, and a different kinesthetic stimulation. On the other hand, where we have *repetition* of

a truly inherited sensori-motor process, we have imitation, but it is not kinesthetic. For example, when a child learns to pile up blocks, (compare Lectures 11 and 12) there is a circular reaction,—imitation in so far as the child imitates a model (a block standing) by creating a thing like it (a block or pile of blocks standing); but the stimulation of the circular process is visual, not kinesthetic. Far from admitting, then, that *kinesthetic imitation* is largely inherited, we are led to deny almost its very existence, even as acquired by experience. Indeed, if it were inherited, it would greatly retard the acquisition of useful habits of reaction. For example, the child, instead of learning how to build a house of blocks, would continue, through the influence of such imitation, to move his hand up and down in the same manner without being influenced by the fact that blocks other than the one in his hand are lying about. Kinesthetic imitation, if inherited, would reduce man's biological significance to something like that of mechanical toys in a child's world, capable only of performing the same jump in endless repetition. There is little probability, then, that such a function should be acquired during life. Kinesthetic excitation as a biological factor seems to be confined to serial motor activity, consisting in a succession of different acts; there, indeed, kinesthetic excitation is indispensable.

While the larger part of the motor activity of an animal consists of reactions upon the objects of the environment, brings about, indeed, in the case of visual or auditory imitation, a duplication of an environmental phenomenon, there are also motor activities which do not seem to affect the objects of the environment at all, and directly, most certainly, do not affect them; which are confined to the inner world of the organism. Motor responses of this class are often called emotional reactions. There is an

enormous literature debating the question what the
emotions are aside from these internal reactions of the
organism, what they are as purely introspective pheno-
mena. Let us be satisfied with the simple statement
that in most, if not all, conditions of animal life which are
called emotional, internal reactions occur; and let us,
without entering into a discussion of introspective "emo-
tions," give a broad classification of them and a brief
discussion of their biological significance.

In order to understand these internal reactions properly,
we have to discuss not only muscular contraction, but also
muscular relaxation, and to regard the latter as a factor
as positive as the former. Lacking space, we cannot
here, and need not for our present purpose, enter into a
discussion of the physiological mechanism by which relaxa-
tion as well as contraction is brought about. Let us
regard either simply as the motor response to a proper
excitation of sensory points. We have then at once two
large classes of internal reactions, according as relaxation
or contraction of the internal organs dominates,—we say
"dominates" as it is entirely possible that relaxation of
some organs be accompanied by contraction in others.
A subdivision of each of these classes is found by reference
to the two classes of muscles in our body, the "organic"
muscles which perform the mechanical work of our internal
organs, and the skeletal muscles which control the position
of the members of the body, relative to each other, and
their motion. The important fact that in the large
majority of all cases of reaction in the organic muscles
reactions in the skeletal muscles occur simultaneously
is comprehensible enough. In general, whenever the
skeletal muscles tend more than ordinarily to relax, the
motion of the body will be unusually weak; and whenever
the skeletal muscles tend more than ordinarily to contract,

the motion of the body will be unusually vigorous.   Thus
we should obtain among those motor responses with which
we are at present concerned, four main classes: (1) Relaxa-
tion of organic muscles combined with vigorous motion.
(2) Contraction of organic muscles combined with vigorous
motion. (3) Relaxation of organic muscles combined
with weak motion. (4) Contraction of organic muscles
combined with weak motion.   It is to be understood,
however, that in no case do we include all the organic
muscles or all the possible motion of the members of the
body.   Let us see, now, to what extent this classification
aids us in characterizing familiar types of emotional
reaction in animals and in man.

Unusual contraction or relaxation of the organic muscles
becomes apparent chiefly in the blood vessels, the heart,
the stomach, the intestine, the bladder, and the skin.
If the ring-shaped muscles of the smaller blood vessels
relax, the vessels take up a larger amount of blood forced
into them by the heart.   The skin, containing innumerable
small blood vessels, then looks red.   Our first class, there-
fore, is illustrated by a person who looks red, whose skin
is warm owing to the presence of a large quantity of
warm blood, and whose motion is very vigorous.   We
recognize in him what we commonly call the emotion of
joy or the emotion of anger.   Whether we apply the one
or the other name, depends on the special situation, which
may call forth—so far as the skeletal muscles are con-
cerned—either movements of dancing, shouting, clapping
the hands, and the like, or movements of attack.   That
the sensory excitation caused by the situation affects not
only the skeletal muscles, but also such muscles as those
in the walls of the blood vessels, is, by the way, a good
illustration of the fact which we have previously emphasiz-
ed, namely, that our nervous system is *one,* in spite of the

special physiological and anatomical names applied for various reasons to its parts. This unity of the nervous system can also be demonstrated by such a simple experiment as this. Address a person suddenly with the question, "Why do you blush?" The response will consist, of course, in words spoken; but in addition, frequently, the person will be observed to blush, although ordinarily stimulation of the auditory organ is not capable of causing a relaxation of the muscles in the blood vessels of the face.

The situation in question, in which we find that person who looks red, etc., probably causes activities of the skeletal muscles which are of a direct objective purpose, for example, running. But it causes also activities of the skeletal muscles which are of no direct purpose, for example, the tension of the facial muscles, the grinning, of a person in joy or rage, often represented by caricatures like Figure 50. Since all the muscular functions with which we are concerned at present, are inherited, not acquired by experience, we may ask how we can understand the evolution of such seemingly useless reflexes. That in anger, where an animal *attacks* another animal, or in joy, where an animal *applies to good use* an object which he has succeeded in obtaining, vigorous motion is biologically of great value, is self-evident. But of what use is grinning?
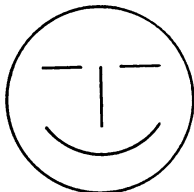

Fig. 50—Tension of the facial muscles in joy or anger.

One answer to the question is this. In anger, grinning may mean simply getting ready to bite, for the mouth is

an important weapon of attack of animals and of primitive man; and in joy, since the most important article applied to good use is an article of food, grinning may mean simply getting ready to bite off and chew.   But it may have still another biological meaning.   It may be of indirect value by helping to bring about social interaction—positive or negative, friendly or hostile—through rendering the situation quickly understood by other members of the animal species.

Let us give further examples to illustrate the indirect, purely social, value of movements or attitudes. In an infant the stimulation of hunger may cause reflex movements of the hands upwards, with the result that the fingers get into the mouth and are sucked, or that the finger nails, when the hands are withdrawn, scratch the face.   Although these results are directly without any value to the child, they are indirectly of the very greatest value, for their sight stimulates the parents to definite activities, for instance, to providing the necessary food for the baby.   A mother describing these reactions would surely say that the baby is "so *hungry* that he tries to put his hands into his mouth," or "so *angry* at the delay of his dinner that he scratches himself."   This social value is not the least significant explanation of the evolution of reflexes which are directly of little value.   There is still left to explain why in situations of joy or anger the blood should rush into the skin.   Perhaps this is merely a symptom of the unusually strong circulation of the blood through the whole body, useful for continued activity of the muscles which, for physiological reasons, would soon be incapacitated for work without being washed out constantly by the blood current.   But the redness of the skin, just as the tension of the facial muscles, the grinning, has also an indirect value of much importance, a value for social interaction.   A red-faced man in a given situation

causes the situation to impress other men in a way by no means identical with the way in which they are affected by the situation while the man in its center looks pale.

The second class of these peculiar motor responses was distinguished by contraction of organic muscles combined with vigorous motion. We recognize the symptoms of what is called the emotion of fear. That the stomach, the intestine, the bladder, and other internal organs contract in a fearful situation, that the heart beats with unusual force, is a familiar fact. Contraction of the smaller blood vessels causes the blood to disappear from the skin and the latter to become pale. Contraction of the minute muscle fibers distributed all through the skin, gives it the appearance ordinarily called "goose flesh"; and where the skin is hairy, this contraction causes the hair to "stand on end." The skin, having lost its blood, cools off, and this cooling in turn calls forth reflexly shivering, the ordinary physiological response to cooling of the skin. The vigorous motion, adapted to the particular situation, shows itself in the individual's running faster than he is ordinarily able to. Vigorous motion, however, is only one external symptom of an extraordinary tendency to contract. Some degrees further, and this tendency results in a cataleptic state, a continuous contraction of all muscles, making all motion impossible. One person or animal responds to a dangerous situation by running, another is "turned into stone."

If we now ask of what biological value these inherited reactions are, we find the answer very readily so far as the extraordinary tendency of the skeletal muscles to contract in response to a dangerous situation is concerned. The faster the animal runs away from the dangerous situation, the safer it is. On the other hand, if the muscular contraction progresses up to the cataleptic, perfectly

motionless, state of the body, the animal is again relatively safe in case the danger comes from another animal being in the neighborhood, owing to the fact that a motionless body is less readily perceived by the eye—not to speak at all of the ear—than a moving body. Many species of birds and small mammals can be observed to assume this motionless attitude when surprised by a man or a hostile animal, especially when the dangerous being is not yet so near that the exposed animal is within direct reach. Many a hunted animal escapes the hunter by this mode of reflex reaction.

Why the organic muscles should tend to contract, however, is less clear. Apparently, their contraction in a dangerous situation can be of no direct value. A certain amount of indirect value, on the other hand, with respect to social interaction, is obvious, especially when the exposed animal is in the cataleptic state. The skin having lost its blood, the exposed animal resembles more nearly a dead animal; and this resemblance may save it. For example, it is reported that certain bears will leave a seemingly dead man's body unmolested; not to reiterate the anecdotes of hunters who gave no attention to an animal whose possession they felt sure of, because it was already dead, but who discovered suddenly that it had run away. Even an animal being chased by another may appear more formidable than it really is, on account of its fur or feathers standing on end, or may retard the enemy by the ejection of disgusting substances.

Our third class of responses was distinguished by relaxation of organic muscles combined with weak motion. This is of all the four classes the least important one. We experience it after having eaten a hearty dinner,—but this is not everyone's habitual occupation. Of vast importance is the fourth class, distinguished by contraction of organic

muscles combined with weak motion. It is exactly the opposite of the first class (joy) and is, indeed, the reaction to any kind of disappointment,—what we most commonly call the emotion of sorrow. We can at once derive the symptoms and comprehend the biological value of this reaction if we recall that in animal life and in the life of primitive man the most ordinary kind of disappointment consists in the want of food. Imagine a winter month: every article which might serve as food covered by snow and impossible to find, for weeks or longer, until the weather changes. An animal which, under these circumstances, would continue to run about for food, would soon fall dead from exhaustion. However adverse the situation, the body can survive living on the substances stored away in its own tissues, if it only consumes this limited supply economically. For this the first requirement is that all muscular activity be reduced to a minimum. Thus we understand why the nervous system, in a disappointing situation, tends to leave the skeletal muscles in a state of relaxation. A person in great sorrow is so far from being master of his skeletal muscles that he drops as if he were completely paralyzed, like Romeo in Friar Laurence's cell:

"Wert thou as young as I, Juliet thy love,
An hour but married, Tybalt murdered,
Doting like me, and like me banished,
Then mightst thou speak, then mightst thou tear thy
    hair,
And *fall upon the ground*, as I do now,
Taking the measure of an unmade grave."

A disappointed person looks like Figure 51 (the opposite of Figure 50), since the relaxation of the facial muscles causes the angles of the mouth to be pulled down by the weight of the lower jaw.

Why should the nervous system, in a disappointing situation, tend to cause contraction of the organic muscles? Recall the animal just spoken of, disappointed in its food supply. If it does not exercise its muscles, little or no heat is produced, for the skeletal muscles are, physiologically, the very furnaces of the body. If little heat is produced, the loss of heat must be safeguarded against. Thus the biological value of the contraction of the muscles in the walls of the blood vessels becomes evident. The
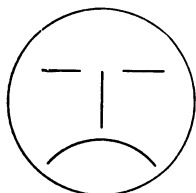

Fig. 51—Relaxation of facial muscles in disappointment.

contraction of the vessels prevents the blood from circulating much in the periphery of the body where cooling mainly takes place. The cooling by the conduction of heat through the tissues covering the body is little to be feared as long as the warm blood is kept in the inner parts of the body and prevented from circulating through the periphery. The actual cooling of the skin, exciting the sensory points of the skin, causes the reflex and habitual response of the animal's seeking shelter, again reducing the loss of heat, of physiological energy. Thus contraction of the organic muscles keeps the animal alive until a change of the external conditions enables it to resume its ordinary manner of life.

Less plain than these reflexes seems the fact that often a disappointed person weeps. From our statements thus far one should rather expect a person in joy to weep, provided we derive weeping from an unusual

blood pressure in the lacrimal glands, an unusual fulness of the blood vessels owing to the relaxation of the organic muscles. Indeed, people weep when joy reaches a high degree. That people weep in disappointment becomes plain when we recall the generally accepted notion that weeping gives relief from excessive sorrow. Only we should rather say: when the nervous system, through normal exhaustion, commences to respond to the disappointing situation less excessively, then weeping occurs. The tears here are actually not a cause, but an effect of relief. The organic muscles, excessively contracted for some time, at the moment when exhaustion of the nervous system commences, relax completely and the blood pressure in the lacrimal glands suddenly rises far beyond the normal.

All these responses of the organic muscles, with or without simultaneous activities of the skeletal muscles, of which we have discussed here only those which can be most easily classified, are the result of nervous connections between certain sensory and certain motor points and group formation among these connections, inherited by each individual of the species. The extent to which they can be modified by experience is slight, almost zero. This is, perhaps, to be regretted, since in the life of modern civilized man they have largely lost the biological usefulness attributable to them under primitive conditions of social life. Nevertheless, however advanced the present evolution of man's nervous system, in his inability to control these responses by experience, man practically shares the fate of the animals.

SIXTEENTH LECTURE

The speech function serving as a generalizing function.
Abstraction a kind of generalization. Advantages of the
written language in generalization for individual use and for
communication. Science the sum total of all generali-
zations which mankind has tested and collected. Written
symbols becoming a class of (artificial) objects to which
man learns to respond as formerly he learned to respond
alone to the objects of nature. Arithmetic. The general-
ization "force" in mechanics: a creation of man like all
other generalizations. Advantage of handling words
rather than things. Danger of speculation.

WE have already discussed speech, but
only as an instance of temporally complex
sensori-motor activity. We shall now
discuss the speech function as that ner-
vous function upon which the distinguishing features of
human as compared with animal life are based. Science
is justly regarded as the chief characteristic of modern
human life. Since generalization and abstraction are the
foundations of science, we shall have to show by concrete
examples what nervous activities are meant when we speak
of generalization and abstraction.

(1) A child, in the presence of such things as bread, fruit,
edible roots, meat, impressing his eye, (S_a, S_b, S_c, S_d in
Figure 52) learns to pronounce the word "food" (M_w in
Figure 52). The nervous function is simply a variation
of response. A new response takes the place of those

which at first succeeded these stimuli and which are indicated in the figure by the dotted lines leading to motor points without lettering. Instead of handling the things
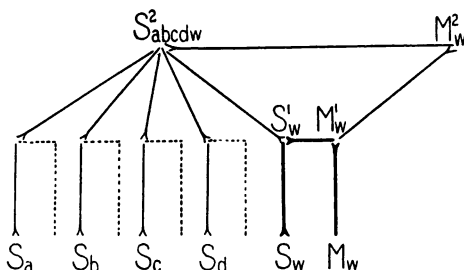

Fig. 52—Naming takes the place of handling.

in accordance with his previous instincts and habits, he speaks the word which is used by older people as the common name of these things. (2) On the other hand, when the child's ear is struck by the sound of the word "food" (S_w in Figure 53), he learns to respond, if otherwise than by saying "food" (M_w in Figure 53), exclusively by
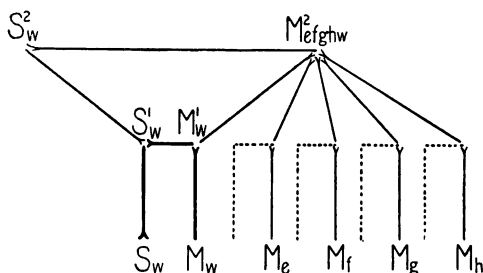

Fig. 53—Handling takes the place of talking.

such muscular activities as are adapted to the preparation for eating of bread, fruit, edible roots, meat, and similar articles and to their consumption by the mouth (M_e, M_f, M_g, M_h). This is also simply a variation of response. The word heard—in any of the nervous functions bringing

about the responses of handling these things—takes the place of the things seen, indicated in the figure by the dotted lines starting from sensory points without lettering. From now on, whenever the word has struck the ear, the muscles which co-operate in properly handling these things get ready to work rather than other muscles to handle other things which also impress the eye at the time. The nervous paths serving the latter impressions are at a disadvantage in not being "cleared for action" by the sound of the word exciting the ear.

Under (1) we mentioned the *speech movement* enouncing the word food, under (2) the *speech sound* of the word food striking the ear. It is plain, then, since the sound of the word strikes also the own ear of the person enouncing it, that the motor response of speaking and the resulting excitation of the ear becomes a double *link inserted* between the mere sight of the article of food and its proper handling.

Sight of thing————————————————————→*handling*
Sight of thing——→*speaking*——→*sound of word*——→*handling*

This insertion of a new link into the chain of functions seems an unnecessary, uneconomical complication due to the individual's experience, so that experience in this case would be harmful rather than useful. It would indeed be an undesirable superfluity of nervous and muscular activity, were it not for the fact that the inserted link is practically the *same* however different the visual appearances of the articles of food—they are all called by this name —and however different the ways of handling and preparing them before putting them into the mouth—they are all called out by the same word food. The insertion between two nervous processes—let us call them *A* and *B*—of such a link of activity, always identical in spite of untold variations of *A* and of *B*, is exactly what we call, in another

terminology, in that of logic, *generalization*. All the visual appearances of things eatable, on the one hand, and all the motor responses of eating (including therein the necessary preparations), on the other, are held together by, are, so to speak, under the command of, a single, though originally not quite simple, biological function of the *speech* reaction class. We understand immediately why in the nervous life of animals there can be little, if any, generalization since animals do not possess speech.

Let us imagine another instance. I, being still an inexperienced child, am occupying a definite position. Another being, animal or human, is occupying another position, more or less distant from mine. I have a solid article, no matter of what kind, in my hand, or between my teeth, or in a pocket, or beneath my feet. A certain stimulation —easily imaginable and therefore needing no definition— causes me to perform such a motion that the article is *transferred* from its place near me to a new place near the other being. While my own motion, as well as the article changing place, impresses my eye, or directly after this impression, the word "give" happens to be spoken in my environment. I imitate the sound and thus learn to respond to the situation of an article being transferred by my own motion from me to another being, by saying "give." But I also learn to respond to the auditory impression "give" by such a motion transferring an article from me to another being. Here, the sum of the motor excitation "give" and the sensory excitation "give" (briefly speaking the speech function "give") is—not, as in the former case of "food," a link inserted between the plain sensory impression of a thing and the motor response of properly handling it—but a seemingly superfluous *representative* of that whole nervous process which has as its issue the motion transferring an article.

Transferring————————————————————————▶*transferring continued*
Transferring————▶*saying "give"*————▶*sound of "give"*————▶*transferring continued*

This representative, accompanying its constituent, would indeed be an unnecessary complication of nervous activity, were it not for the fact that the additional function is practically the *same* however different the manner of motion transferring the article in question: by stretching out the hand, throwing, kicking, dropping from an elevated place, rolling down a hill side, not to mention sending it by a messenger, by mail, or by any other device of modern transportation. This establishment of a definite function identical in spite of untold variations of the sensori-motor activities which it represents—they are all called giving—is obviously also a generalization. Or, in the terminology of logic, it is an *abstraction*. Abstraction, then, is a special case of generalization—generalization, not with reference to objects, but with reference to *relations* (spatial transference, in the instance discussed).

The difference between the biological functions in ordinary generalization and in this special kind of generalization, abstraction, might be described thus. In ordinary *generalization* the *object handled* is of main significance. The manner of handling it is of importance only in so far as the object is distinguished from objects of a different class by the proper mode of handling it,—for example, "food" is an object to be eaten by the responsive animal. In *abstraction* the *mode of handling* is of main significance. The object itself is important exclusively in so far as, if there were no object whatsoever, no handling of it could have occurred.

The purpose of our present discussion is not to give a lesson in logic. Our intention is to show briefly, but conclusively, that practically no generalization or abstraction is possible without speech, and to make clear by concrete examples what is meant biologically by such terms

as generalization and abstraction. In order to make the significance of the speech function for the nervous activity of the *individual* living body—over and above the *social* significance of speech as a mere system of signals for co-operation in actual labor—still clearer, let us make a third application to a concrete case of human life.

A child, having had both the speech experiences above described of "food" and of "give," happens to meet another person, say, a beggar, who addresses him with the words "food, give." The natural consequence is, first, that the child looks about until his eyes are arrested by an article belonging to the class of "food," say, a piece of bread. Then he approaches the bread and would now respond to its sight simply by the most firmly established habit, by taking and eating it, had his ears not been stimulated by the sound of the word "give" too. So he responds to the total stimulation of sound and sight by giving the piece of bread to the other person. Similar occurrences take place quite frequently in the child's life; but the words heard are not always only food and give. Now and then the address will be "food, give, hungry." Thus the child learns, by what we have called a variation of response, to react to the word "hungry" in the same way as to the sentence (if these two words may be called a sentence) "food, give." He learns to react to the word hungry by looking about for edible things, taking hold of them, and transferring them to the other person. What a wealth of possible actions is thus placed under the control of the single word "hungry"! The fully experienced human being, hearing this word, looks about until an edible thing strikes his eyes. But if his eyes do not perceive anything eatable, other activities follow. He may put his hands into his pockets to search for food. He may walk home in order to find food there. He may open

his chest or cabinet, take money from it, and go to the store where food is for sale. Or he may go out to his fields, cut his wheat, and store it away under the roof of a barn in order to be able to give food at a later time when the sound hungry may strike his ear again. Not having any wheat mature on his fields, he may take out his horses and implements and plow the ground on which wheat is only to be sown. He may attend, as a student, an agricultural college where he learns how to grow wheat most successfully on his farm. He may vote in favor of his government spending money for the support of such a college. Further think of the innumerable possible activities which make provision for the transportation of the food from place to place, from the producer to the consumer! To enumerate even those activities which are more directly controlled by the word hungry, would require a volume. Of the activities which we have mentioned, some are rather remotely dependent on the abstraction "hungry". The more remotely they are dependent on it, the more numerous, of course, are the other abstractions on which they are also—more or less directly—dependent, so that, then, the actual motor response becomes more and more the resultant of many components, of all the activities controlled by all the abstractions.

We have thus far spoken of the word "hungry" only as denoting a sound, stimulating the ear and controlling by means of the nervous paths diverging from the ear a vast number of highly complicated motor responses. We said above, that the word hungry was often heard together with the words food and give. At such a time it must have been imitated by the child in question. Thus the pronunciation of the word hungry has become one of the possible motor responses to the total situation. It is plain, however, that the same word, hungry, is also heard

in other situations, especially frequently at the time when the subject together with the other members of the family takes one of his regular daily meals. At that time the sensory points of the stomach are likely to be excited by the physiological condition which is called hunger. Accordingly, the subject learns to say "hungry" in response to the sensory excitation of hunger. Whenever he responds thus, he produces the sound of the word, and this sound impresses his ear. Most naturally, then, the total (motor and subsequently sensory) speech function of the word "hungry" becomes an intermediate link between the sensory excitation of hunger and that vast number of responses mentioned above, all serving, with greater or lesser directness, to dispel hunger not only in others but in himself.

What, then, is the value of abstractions to man? They serve to make ready, instead of the simple reflex or instinct corresponding to the stimulation, an enormous number of complex motor responses among which a selection is made by the other sensory factors of the situation and the motor tendencies of the abstractions belonging to them. This complex nervous activity, which is *the distinguishing feature of man's life* as compared with that of animals, is made possible by the acquisition of speech.

In this development, now, of generalized (abstract) nervous functions an enormous step in advance is made when mankind invents script. Not only can the written language—except for the greater brevity of speech than of writing—in the functions described above almost completely take the place of the spoken language; it can even accomplish much that is denied the spoken language. First, it enhances preservation of the individual's generalizations (including his abstractions) for his own later use. Secondly, it removes practically all limits of space and time from

communicating one individual's generalizations to other individuals.

As to the preservation of any generalization for the individual's own use, it is plain that, as long as generalization is mediated only by the spoken language, it depends exclusively on the properties of his own nervous system. Just so long will the generalization persist, as a path of low resistance, established by the speech function, leads from the sensory points of, say, hunger to a common central point, and another one from a common central point to that vast number of responses previously indicated. But such a path of low resistance can continue to exist only if it is constantly re-established, so to speak; for we know that a path whose resistance has been lowered by individual experience tends to resume gradually its original high resistance. After the individual has acquired—by a simple variation of response—to the sight of the written word the same manifold possibility of responding as to the sound of the same word, the time limit of preserving the generalization depends no longer on the delicate properties of his nervous system, which is so easily influenced by new experiences as well as by normal and abnormal physical processes like fatigue and disease, but on the physical properties of the material on which he has written the word. It is true that, quite recently, one has learned by phonographic records to preserve even the spoken word. But the limitations of this method are obvious, and, whatever may be its significance for the future, in the past at least the individual has had to depend for the preservation of his generalizations on the written word, the memorandum-book. Of course, we use here and in the following the term "word" in a very wide sense, including therein all written symbols of any kind, especially those of mathematics, even all kinds of geometrical drawings, and

the diagrams and symbolic letters of physics, chemistry, and all other sciences.

Secondly, we stated that by the substitution of the written for the spoken word communication of the individual's generalizations to other individuals has transgressed almost all limits of space and time. As we read a letter despatched from the opposite side of the globe, we learn what generalizations were most powerful in the nervous system of the individual who signed the letter, at the time—weeks ago—when it was written. As we peruse the book of an author long since deceased, we learn what generalizations of his own he thought desirable to communicate to his contemporaries and those who were to live after him. As we uncover the tombs of the Egyptian kings, we learn what generalizations chiefly determined their actions thousands of years ago, while they were preparing for the common destiny of all individual life, for death. Posterity, opening our books, may learn what generalizations affected our nervous system so strongly that, in addition to using them in our individual life, we had them reproduced in the printer's office. Thus all mankind becomes a unit, spatially and temporally. The individual's experiences are no longer useful to him and to the few people of his direct environment alone. All other individuals of the present and future may profit by them. Thus only, mankind becomes in the world of animal life that power the vastness of which nothing perhaps testifies as much as the existence of poetry and religion. But to the growth of this power neither poetry nor religion contributes directly. Its systematic furtherance is the task of science. Science is the sum total of all those generalizations which the experience of mankind has invented, selected, and collected as the most useful for the control of the muscular response called forth by sensory excitation.

The statement of the last sentence calls for further elaboration since the work .of a scientist, especially to those not very familiar with it, seems to be altogether different from that of the ordinary man, say, the farmer plowing his field,—seems to belong to a category of activity other than that of motor (muscular) response to sensory excitation.

When, in the evolution of civilization, the writing of words and other symbols of generalization has firmly established itself in a sufficiently large group of men, in a tribe or a nation, the written symbols become a special class of important objects to which, however artificial their origin, man has to learn to respond in order to be successful in the struggle for life, as formerly he had to learn to respond to those objects alone which have their origin in nature. Moreover, young people selecting a class of objects to which to devote their lives as specialists may now not only select from the natural objects, but may choose even this class. Their life work, then, consists in responding to written symbols by writing symbols and, of course, also by pronouncing them, as in oral teaching. The scientist's work, aside from experimenting, that is, testing the value of his generalizations by skilful appeals for an answer to nature, consists in combining, on writing paper, symbols already existing into new groups and inventing for each group of generalizations which has been demonstrated by experiment to be a useful combination of symbols, a new name, that is, a new symbol of generalization. All this is, clearly, motor activity in response to sensory excitation. The only distinguishing features are these, that the scientist's motor activity does not require muscles of any great strength, and that it does require an enormous amount of learning, of variations of response, before it can begin to be of any value to humanity.

Let us take an example from the most ancient of all the sciences, which, notwithstanding its age, is still and will always be the foundation of all others,—from arithmetic. No one doubts that the most ancient symbols for larger and smaller groups of things were diagrams of familiar objects. The Roman numerals V and X, for example, are diagrams of one hand with fingers spread out and of two hands united in opposite positions at their wrists. Even if these diagrams, originally, signified only a quantity portable in one hand and a quantity portable in both, they would already be generalizations, for many are the things or substances which can be carried by hand. If not at once, at a later period, these diagrams came to signify five and ten. They are then a step further removed from natural experience; they have assumed to a further degree the meaning of a generalization (or, if you prefer, of an abstraction). When a person counts, up to five or any other number, he enounces in regular order one of the words of a series which he must previously have learned, while he removes to a position of repose, say, with his finger on the table, or with his turning eye in the subjective field of vision, just one more each time of the objects counted. The series of words spoken in doing this (that is, the series of numbers) is a generalization since it represents innumerable different manners of successively removing the objects, only two of which (by the finger and by the eye) have been mentioned above. When written symbols like our Arabic figures are substituted for the spoken words, new generalizations are made possible. What is the significance of the plus sign? If we write it in 7+8, we invite the reader to count a group of seven things of his own choice and another group of eight as if they were only a single group of countable things. The plus sign, then, is a generalization for any kind of sensori-motor

activity arranging the things as if they were a single series and counting them thus. The minus sign is a generalization of a similar kind. In $7-4$, for example, we express the question: How many times more do you count after 4, till you enounce 7? The minus sign, then, is a generalization for any kind of sensori-motor activity arranging the things of one series as if they were two series. The multiplication sign presupposes the experience of the plus sign. By writing 3×7 we invite the reader to perform the work of adding 7 plus 7 plus 7. Modern mathematics has greatly increased the number of such generalizations,—think only of logarithms, not to mention higher mathematics. Yet by degrees they can all be reduced to the relatively simple sensori-motor activity of counting a series of things.

Another example of a scientific generalization might be taken from mechanics. Remember the formula $\frac{1}{2}mv^2$, generally used in measuring our experience of "force." Man, in his intercourse with nature, learns how to resist moving objects and also how to utilize the motion of objects (a hammer, for example) for his own purposes. He learns that he has to exert more muscular energy if the object resisted is heavier, and also that his work is more effective if he uses a heavier tool. He generalizes his experiences of resistance to objects and of work by the aid of objects—experiences to which he has already given the general name of "force"—by pronouncing the word "mass" in order to express their quantitative aspect. In writing this word he abbreviates it by writing simply m. By further experience man learns that he has to exert more muscular energy and also that his work is more effective, if the object in question moves more quickly. These experiences, in addition, he generalizes in writing by uniting the symbols "mass" and "velocity" in a single

formula, connecting them by a sign of multiplication. At our present time, however, one does not write simply $m \times v$, but $m \times v^2$, multiplying v with itself. This is done because the formula $m \times v^2$, in algebraic relations with other formulas expressing other important experiences with heavy bodies, is in general more convenient. Still, this greater convenience was only gradually recognized by scientists. Two hundred years ago the question was debated in heated controversies between the most distinguished scientists whether the symbol mv or the symbol mv^2 was a more useful tool of generalizing human experience, or, as they expressed it,—talking as if force were a measurable thing among the other objects in nature, instead of a mere generalization invented by man—"whether force was proportional to velocity or to the square of velocity."

At present the latter formula is generally preferred, but slightly modified by the addition of the factor $\frac{1}{2}$. This simplifies again the algebraic operations, for the formula $\frac{1}{2}mv^2$ can be put down directly as equal to a certain other very important formula of mechanics. The usefulness of the equation thus formulated is the only reason why our scientists have become accustomed to using exclusively the formula $\frac{1}{2}mv^2$ in their generalizations of the quantitative aspect of the qualitative generalization of "force." (We may mention, by the way, that the use of the equation in question gradually brought about a change of name of the generalization $\frac{1}{2}mv^2$, so that it is nowadays called "work" in the text-books of physics.)

Force, therefore, is by no means, as some speculative philosophers would make us believe, a reality given by nature, and truly measurable only by a single formula, but a mere abstraction created by man to suit his needs, and expressed by that combination of algebraic symbols

which best suits his needs, practical and theoretical,—
an abstraction from experiences so varied and complex
that without this generalization we could not respond to
the quantitative aspect of any one of them with any defi-
niteness, we could not measure them.

In school and all through life we find ourselves compelled
to respond to traditional audible and visible symbols of
generalization as well as to the situations presented by
nature. We gradually learn to respond to these kinds
of stimulations most successfully: we acquire scientific
habits. An example of a habit of responding to symbols
of generalization—or rather an example of a large group of
such habits—is the multiplication table. To the phrase
"seven times nine" we at once add, by habit acquired,
the word "sixty-three," without having first to do any
counting, thus saving a large amount of time. In a
similar way one learns, long before he acquires the
multiplication table, to combine words into sentences and
sentences into periods, and to draw conclusions expressed
in further sentences, without first having to devote time
and energy to perceiving the things which are meant by
those generalizing words and sentences. The enormous
advantage of substituting this handling of words for the
cumbrous handling of things is clear enough, but the
danger of speculation is clear too,—the danger of combining
words and of thus drawing conclusions, that is, of expect-
ing the things to agree with the last group of words
manufactured by us, for no better reason than this, that
we know our succession of sentences to have been construc-
ted according to the rules of grammar, syntax, and logic.
This danger does not exist in the case of the multiplication
table. Here, in our most elementary quantitative generali-
zations, things always agree indeed with our conclusions.

But our purely qualitative generalizations are so inexact that the things, when we perceive them, often turn out to be quite different from what we, guided only by our habits of handling words, expected to find them.

The generalizing function changing from a nervous and muscular into a purely nervous function. Relation between processes in the higher nerve centers and strictly subjective experiences. Nervous functions of generalization especially likely to have also the subjective aspect. For the generalizing nervous function in another person's brain we substitute an imaginary mental state. The nervous correlates of sensation and imagery. Associations of successive and of simultaneous mental states. Attention. Pleasantness and unpleasantness. Insufficiency of introspective psychology.

WE have discussed, in some detail, the biological significance of spoken and written language. We stated that practically no generalization is possible without speech. We showed that generalization, regarded as a biological function, comes about by the insertion of an additional link in the series of organic processes previously existing, and that the link added is a double link, a motor response, speaking, and a sensory excitation, the sounding word. One must not conclude, however, that consequently in every process of generalization the subject must actually speak the word upon which this generalization is based, that is, must innervate and move his speech organs. No doubt, generalization in general has its origin in actual speech. But the speech function in all generalizations tends to change during use from a nervous

and muscular function to a purely nervous function; and a highly educated individual may even originate generalizations without at all calling his speech organs into play.
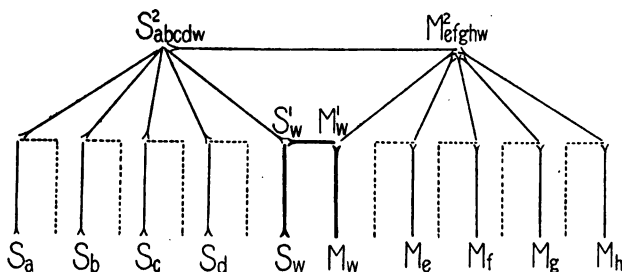

Fig. 54—Generalization without actual speech.

Figure 54 helps us to understand the dropping out of the muscular function. The figure is a composite of Figures 52 and 53. In discussing the latter figures we showed that an excitation by any article of food of any one of the sensory points to the left (in Figure 54) may call forth a response at any one of the motor points to the right by mediation of M_w and S_w, since the reaction at M_w, the organ of speech, results in a sound and thus in a physical stimulation of S_w, the ear.

In this way any article of food appearing before the eye or another sense organ tends to call forth any action of preparing for a meal and eating. Now, a glance at Figure 54 teaches that the generalization, as soon as established, no longer needs the peripheral points S_w and M_w, essential to its creation. A nervous excitation starting from S_a, S_b, S_c, or S_d can directly over S^2_{abcdw} M^2_{efghw} take its path to M_e, M_f, M_g, and M_h. The functional relation to the points S_w and M_w of this direct path is then merely historical, consisting in the fact that *a part of the path from, say, S_a to M_h* (namely, the part from the point

$S^2_{ab\,cdw}$ to the point M^2_{efghw}) *has in the past been traveled over by nervous processes coming from* S_w. A fact of this kind we shall soon find to be of a particular significance.

We have just seen that no actual speaking, nor writing either, is required for the functioning of a generalization once established. The biological function of generalization may be regarded as purely nervous. Moreover, it is a nervous process inevitably taking its path over higher—very high—nerve centers. Between nervous processes in the higher nerve centers and strictly subjective experiences, that is, the individual's states of consciousness, there is an important relation. We have good reason to believe that a mental state never occurs unless there is at the same time a nervous process taking its path through the higher nerve centers. It is probably not correct to call the relation between a mental state and a process in a higher nerve center causal, which would mean that the one occurs first and the other after, or the other first and the one after. More probably they are strictly simultaneous; but we are as yet unable to prove it because science has not yet invented an instrument by means of which we can observe the process going on in our own brain while we have the mental state corresponding to it. If they are strictly simultaneous, we have the right to describe them by saying that they are really only one phenomenon occurring in the world, but that this phenomenon has two aspects. In so far as it can be observed by any and all individuals, including the one whose brain is affected, who are in possession of the proper instruments (not yet invented), we call it an objective phenomenon, a nervous process. In so far as it is (and can be) known exclusively by the one individual whose brain is affected, we call it a subjective phenomenon, a mental state. We understand, then, that among all the possible nervous functions those

of generalization are especially likely to have also the second, the subjective aspect, because they occur in very high nerve centers.

This brings us back to the considerations with which we started out in the first lecture. We stated there that in pronouncing a moral judgment on a boy who has obstructed the track of a train, we seem to be interested chiefly in his thoughts, although only his actions, never his thoughts, can be known to us by observation. When in school, we seem to be interested chiefly in what our teacher thinks of us, although only his actions can be observed by us. The path is now open for our understanding this.

The proper valuation of the boy's or the teacher's action depends on the application of the proper generalization. It really does not matter much whether the boy placed a plank on the track by using his hands, or caused a rock to roll on the track by using his feet, or, by using his speech organs to pretend a different purpose, made a friend put a stick of dynamite there. What matters is only the fact that all these events are likely to cause the derailment of a car. The derailment, again, is not of so much importance for our judgment as the fact that the derailment may be the cause of many different events, the saving of a train from passing on a bridge with underwashed foundations, the killing and maiming of numerous passengers by the destruction of the car, and innumerable others. Our judgment, then, is impossible without generalization. It is itself a generalization of a high order. It expresses our decision as to *what generalizing function determined the boy's motor activity*, whether he said to himself (remember in Figure 54 the points M_w and S_w!): "I will save" or "I will kill."

As we found in the preceding lecture, however, it is not necessary that the boy actually pronounces the word. It leads to the same motor result if the particular generalizing function on which our judgment has decided, is purely nervous, a nervous process passing through a certain higher center in the boy's brain. Therefore, if our judgment were in every respect what it ought to be according to the standards of exact science, it would plainly express that this generalizing process occurred in this high center of the boy's nervous system. But, unfortunately, these nervous processes in the higher centers are only hypothetical, owing to the fact that the instruments for their observation have not yet been invented. That they will have been invented in a hundred years, or sooner, or later, does not help us. So we help ourselves by substituting in our imagination for the boy's nervous process which today the undeveloped state of physiology will not let us know, an assumed reality which we do not, shall not, cannot ever know, a *mental state* of the boy, his willing to save, or to kill. The right to substitute this assumed mental state, in spite of its being forever unknowable, for the nervous process, which is insufficiently known only because of the insufficient development of scientific technic, we derive from the fact that a (slightly familiar) nervous process like the boy's is in each of us, individually, regularly coexistent with a perfectly familiar state of willing to save or to kill.

In a similar way we substitute in our imagination for the nervous process determining our teacher's actions a mental state taken from the store-house of our subjective experiences. Objectively, scientifically, we know only our teacher's actions. We are not so much interested, however, in the particular act as in the class to which it belongs. We do not, for example, care so much whether

he uses his writing hand or his talking mouth to praise us, as we care for the general fact that he praises us and does not blame us. It is, therefore, *the generalizing nervous function in a high center of the teacher's brain that concerns us.* And for this nervous function we substitute, for reasons stated, *an imaginary mental state,*—imaginary since, not being ours, it is unknowable to us.

From this it must be clear that there can be little scientific progress in our knowledge of the interrelations between human beings until we shall be able to comprehend better the nervous processes of generalization which almost exclusively determine these interrelations, our social intercourse. But since we shall undoubtedly continue, for a long time to come, to substitute in our discussions of social events for the generalizing nervous processes imaginary mental states, it is important that we understand how in our individual life nervous processes and mental states are connected. We emphasized on page 209 that (in Figure 54) a part of the path of the generalizing function had in the past been traveled over by nervous processes coming from S_w. Let us note that stimulation of S_w is stimulation by a word, and let us remember the extraordinary part played in any generalizing function of our individual consciousness by word imagery. We draw the conclusion that *our consciousness* of the word-image, when any of the points S_a, S_b, S_c, or S_d in Figure 54 is stimulated and responded to by any of the points M_e, M_f, M_g, or M_h, has *its nervous correlate* in the fact that a part of the nervous path taken by the excitation has previously been traveled over by a nervous excitation coming from the sensory point S_w corresponding to the particular nature of this word image (auditory, visual, etc.), while S_w remains at present unstimulated.

Thus we can at once establish a general rule concerning the nervous correlate of sensation, on the one hand, and of imagery, on the other. Sensation, we know from our individual experience, requires proper sensory stimulation, but requires also, we have good reason to believe, that the nervous excitation takes its path, not directly over a reflex arch, but over higher nerve centers; otherwise there is no consciousness. It is a common condition, then, for the existence of either sensation or imagery, that the nervous process does not remain in the lowest centers, but takes its path over higher nerve centers. The difference, whether our consciousness is a sensation or an image, depends on this: If the nerve center which is conducting a nervous excitation, *is at present serving the sensory point* corresponding to the mental state in question, that mental state is what we call a *sensation;* if the center *has only in the past served the sensory point* corresponding to the mental state in question, that mental state is what we call an *image*.

Introspective psychology, that is, the psychology which restricts its observations to (the observing individual's) consciousness and attempts to comprehend human life by comprehending the one individual's life, has long ago formulated one important law, that of the association of mental states. An association may be one of successive or of simultaneous mental states. In the former case, "association" means that the particular mental states tend to recur in the same order, or, more rarely, in reversed order. In the latter case, "association" means that the particular mental states tend to occur together at one moment rather than temporally separated from each other. Let us state, in the terms of nervous function employed in these lectures, the nervous correlate of the law of association.

A nervous process starting from a certain sensory point, say, S_a in Figure 16, terminates and is succeeded by another nervous process starting from S_b. This second process is then not uninfluenced by the first. A larger fraction of its flux takes its path over the connective neuron $S_{ab}^2 M_{ab}^2$ than would have done so if the other flux had not a moment ago been conducted partly by this neuron. (We have discussed this same fact in Lecture 10 with a somewhat different end in view, namely, in order to show that a nervous process can be more or less deflected not only by a simultaneous stronger one, but also by any directly preceding one.) When now, at any later time, S_a is stimulated again, more of the flux passes up from S_a^1 to $S_{ab}^{2'} M_{ab}^2$ than the first time, since the resistance of the higher center $S_{ab}^2 M_{ab}^2$, affected by two nervous processes, has been reduced relatively more than that of the lower center $S_a^1 M_a^1$. If we represent by $S_a^1 M_a^1$ a relatively high center, (relative to the whole system), the flux in $S_a^1 M_a^1$ must be accompanied by consciousness. The nature of this consciousness is determined by the nature of the sensory excitation at S_a. The flux in the still higher neuron $S_{ab}^2 M_{ab}^2$ is accompanied by the same consciousness, but also by the consciousness corresponding to the nature of the sensory excitation at S_b, because $S_{ab}^2 M_{ab}^2$ has been traveled over previously by a nervous process coming from S_b. It is clear that the mental state "b" must begin later than the mental state "a" since the relief of tension starting from S_a can not reach the point S_{ab}^2 as soon as the point S_a^1. The successive association of the two mental states is therefore a simple consequence of our assumptions concerning the laws of nervous function. ·

What we have just said about two mental states of a successive association, holds equally for three, four, etc. Nothing new is to be found in these cases, except that, the

greater the number of different sensory excitations (for example, add S_c and S_d in Figure 16), the higher are the nerve centers coming, more or less, into play (up to $S_{abcd}^4 M_{abcd}^4$ in the same figure). This is evident enough. Another fact, however, deserves probably a brief discussion, that of reproduction of the mental states in the order opposite to the one in which they were acquired. The classic treatise of Ebbinghaus "On Memory" proves the existence also of a tendency for reproduction in the reversed order. The nervous correlate of this tendency is easily derived from the same example which we have just used. If S_b alone is stimulated, after the succession of stimulus "a" and stimulus "b" has had its opportunity for changing the relative resistances of the higher centers in Figure 16, the nervous excitation travels, not only over $S_b^1 M_b^1$ but also considerably over $S_{ab}^2 M_{ab}^2$. The flux in the centers $S_b^1 M_b^1$ and $S_{ab}^2 M_{ab}^2$ is then accompanied by two mental states, "b" occurring first because the center $S_b^1 M_b^1$ can be reached from S_b in less time than $S_{ab}^2 M_{ab}^2$. That is, the mental state "b" calls up the mental state "a" although in all the instances of twofold stimulation "b" was invariably preceded by "a."

Ebbinghaus rightly points out, however, that this reproduction of mental states in the order opposite to that of their acquisition by the individual is quite rare. He explains it by calling attention to the fact that, as a rule, the two mental states are members of a series and are followed by other mental states. In the alphabet, for example, "b" but rarely calls up "a," because its tendency to call up "c" is still greater. Let us explain the same fact in terms of nervous function by the aid of Figure 55. If in the mental process of memorizing the letters of the alphabet or any other series S_q is stimulated soon after a flux from S_p has occurred in the center $S_{pq}^2 M_{pq}^2$, the part

of the flux which does not take its path from S_q^1 to the right but upwards, must divide so that more passes in the direction of S_{pq}^2 and over the center $S_{pq}^2 M_{pq}^2$ than in the direction of S_{qr}^2 and over the center $S_{qr}^2 M_{qr}^2$. We may say, then, that from any of the points S^1 a larger
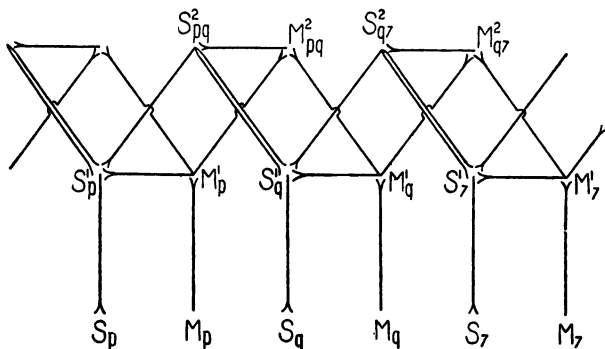

Fig. 55—Two directions in successive association.

flux travels up to the left than up to the right. This is indicated in Figure 55 by double and single lines. It is then immediately clear that during the memorizing any one of the neurons marked $S^2 M^2$ receives from the right below a stronger flux than from the left below. For example, $S_{pq}^2 M_{pq}^2$ receives relatively a strong flux from S_q, *a weak flux from* S_p; and $S_{qr}^2 M_{qr}^2$ receives *a strong flux from* S_r, a weak flux from S_q. On some later occasion S_q alone is stimulated, say, for the sake of a test. The flux divides at S_q^1. A part travels over $S_q^1 M_q^1$, another part over $S_{pq}^2 M_{pq}^2$, a third over $S_{qr}^2 M_{qr}^2$. Our problem is to show whether of the mental states other than "q," namely "p" and "r," the one or the other has a higher degree of consciousness. Obviously, the degree of consciousness depends on the relative flux which has previously passed over the higher centers $S_{pq}^2 M_{pq}^2$ and $S_{qr}^2 M_{qr}^2$ from S_p

·and S_r. Above we found that the previous flux over the higher centers from S_r was relatively strong, from S_p relatively weak. Accordingly, the mental state "q" tends to call up the associated mental state "r" rather than the associated state "p." Thus we have explained this rule of introspective psychology in terms of nervous function.

To explain in terms of nervous function the simultaneous association of mental states, it is only necessary to refer to our discussion of that kind of variation of the nervous path which we called motor condensation. If a number of sensory excitations unite in a higher center in order to pass into a common motor outlet, the condition for a simultaneous association of definite mental states is fulfilled. Whenever now, even from a single sensory point, a nervous process travels over that center, the mental states corresponding to all those sensory excitations must simultaneously enter consciousness.

Aside from the time-honored law of association, only one other generally recognized law of mental life has been discovered by purely introspective psychology, the law of attention. By *attention* is meant "the peculiar fact that of a great number of conscious impressions or ideas simultaneously offered to the mind, only a few can ever be carried through and become effective." It is plain that, in terms of nervous function, this is the law of *deflection* of weaker nervous processes by a stronger one. The stronger nervous process determines the dominant aspect of the total mental state. The weaker ones, if deflected from their own course before having reached any centers of a higher level, are not accompanied by any consciousness whatever. The higher the center reached by any of these nervous processes before it enters the path of the stronger process, the more pronounced, relatively, the corresponding consciousness; the greater,

obviously, also its chance of becoming later the prevailing
nervous process itself and determining the animal's next
action.   Thus we must expect to find by introspection
in our individual mind as a rule a single mental state
dominant together with a large number of others of vary-
ing degrees of consciousness.   The law of attention, which
has caused introspective psychology so much discomfort,
and which Herbart attempted in vain to clear up by his
"mechanics of ideas," thus becomes clear enough as
soon as we comprehend its nervous correlate.

Introspective psychology has long struggled to under-
stand the relation between the feelings of pleasantness and
unpleasantness (not meaning by the latter term "pain,"
which is a sensation) and human behavior.   It seems ad-
visable to approach the problem from another point of
view, studying objective nervous functions, hypothetical
as they may be for the present, rather than the intro-
spections of the individual which by their very nature
can never be anything but subjective.   We can distin-
guish two classes of conflict between two nervous processes
of which one originates while the other is still going on.
Either, the first is stronger, deflects the second and by
absorbing it grows still stronger.   This corresponds to
our experiences of pleasantness, for in all such experiences,
however varied in other respects, we continue the same
form of behavior more and more vigorously.   Or, the
second nervous process is stronger, weakens the first by
deflection, and finally absorbs it completely.   This cor-
responds to our experiences of unpleasantness, for in all
such experiences our behavior suffers interference until
it is completely replaced by another form of behavior,
when the unpleasantness ceases.   The nervous correlate
of feeling may then be described in the following words.
The nervous correlate of *pleasantness and unpleasantness*

is the increase or decrease of the intensity of a previously constant nervous process if the increase or decrease is caused by a force acting at a point other than the point of sensory stimulation. The condition of the second half of this sentence is necessary because our experiences of feeling do not depend on a change in the intensity of a stimulus, but on the interference of nervous processes in higher nerve centers.

Introspective psychology, disregarding *behavior*, for centuries has been satisfied with remarking that pleasant experiences are the experiences of helpful *situations*, unpleasant ones those of harmful *situations*,. This is true enough, for the animal body is so equipped by nature with nervous connections of sensory and motor points that reactions to a helpful situation continue and grow stronger, reactions to harmful situations are weakened until they discontinue. But there are exceptions to this rule which destroy its whole value for any mental or social science, for it is an undeniable fact that the pleasure-seeker may sacrifice his life to pleasure. Not the study of the individual's consciousness, of "the structure of the mind," but the study of the nervous laws of behavior will enable us to understand the significance of human action for human life in the individual and in society. The scientific value of introspective psychology consists merely in the fact that it aids us in discovering the laws of nervous function.*

How unreliable the results of introspective psychology are, can be learned, for example, from the attitude of

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*A more detailed account of the relations between mental states and nervous functions may be found in my articles "The Nervous Correlate of Pleasantness and Unpleasantness" and "The Nervous Correlate of Attention," *Psychological Review 15*, 201-216, 292-322, 358-372; *16*, 36-47. 1908-9. Compare also an elaboration of this theory and application to sociology by L. L. Bernard, "The Transition to an Objective Standard of Social Control," The University of Chicago Press, 1911.

psychologists toward the question as to the relative importance of the kinesthetic sense. When, during the nineteenth century, sensory neuron endings were discovered in muscles and tendons, some psychologists made use of the new sense in order to explain numerous phenomena whose explanation had formerly been impossible. Immediately they were opposed by others who asserted that the kinesthetic sense was of practically no significance since in their individual consciousness they could not, introspectively, discover any kinesthetic sensations or images at all. We saw in Lecture 13 that kinesthetic sensory activity is quite indispensable for the training of any temporally complex reaction, for example, speech. Introspective psychologists, however, are rarely among those people who—like mechanics, skilled factory workers, sportsmen, and athletes—acquire new habits of temporally complex reaction late in life. Their own habits of this kind were all acquired in early childhood and have long ago become completely automatic,—short-circuited, so to speak. Since the nervous processes of these reactions no longer pass over higher centers, there can then be little consciousness, especially no consciousness of kinesthetic sensation or imagery. It does not follow, however, that this consciousness was absent in their first few years of life when they received all the motor skill they possess; and it does not follow that the kinesthetic sense during any period of life is insignificant as a nervous function. This is, perhaps, the best example one can find of the failure of introspection in the explanation of human behavior.

Enormous is the amount of introspective research embodied in the publications belonging to the mental and social sciences from Aristotle to the present day, enormous the energy which has been spent on careful analysis of

introspective records by the application of generalizations, of abstractions. But if one attempts to collect results of these investigations which are generally recognized— or recognized at least by a majority of the scientists of the present day—as contributing toward an understanding of human life in the individual and in society, he is struck by the fact that there is almost nothing to be collected.

A few abstractions are recognized as valuable for the science of general psychology: memory, association, attention. In the special mental sciences, ethics, education, sociology, politics, political economy, little— aside from purely statistical facts—seems to be more than personal opinion. There appears to be only one hope that a real mental and social science, comparable to natural science, will ever come about, the hope based on the observation that just as far as the facts and laws of introspective psychology have hitherto been correlated with—replaced by—facts of behavior and its laws, has confusion and obscurity given place to order and clearness in the mental sciences. There is hope, then, that by future progress in our knowledge of the laws of human behavior more order and clearness will be there introduced.
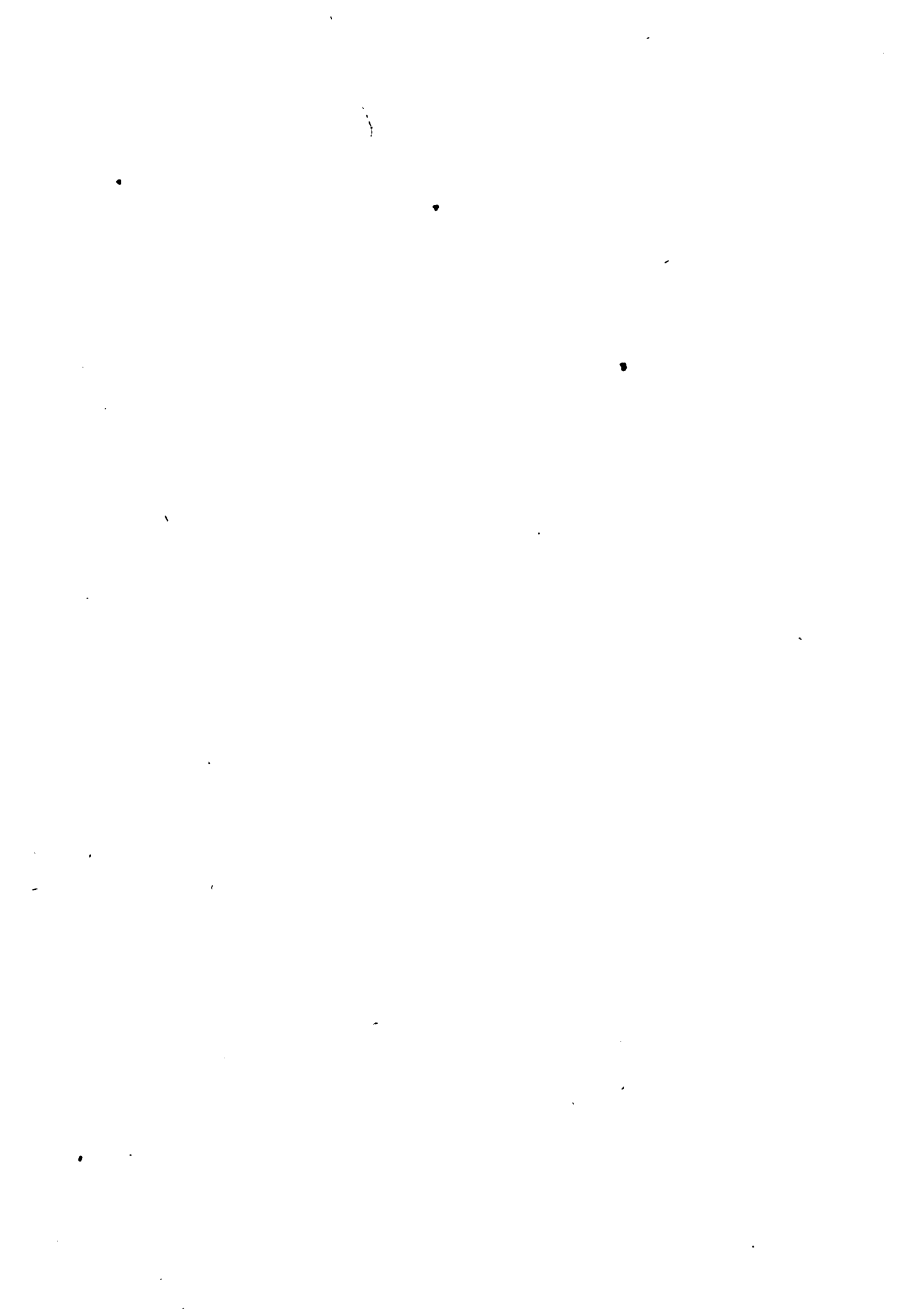
TRANSLATIONS

Adolf Hildebrand, The Problem of Form in Painting and Sculpture; translated and revised with the author's co-operation by Max Meyer and Robert Morris Ogden. G. E. Stechert & Co., New York. 90 cents net.

    The famous sculptor of Munich, Germany, describes in this book the mental processes which dominate his own artistic activity.

Hermann Ebbinghaus, Psychology; translated and edited by Max Meyer. D. C. Heath & Co., Boston. $1.25.

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